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Multimedia Environmental Control Engineering Handbook Methodology and Sample Summary Sheets

Cameron Engineers, Inc, Denver, CO

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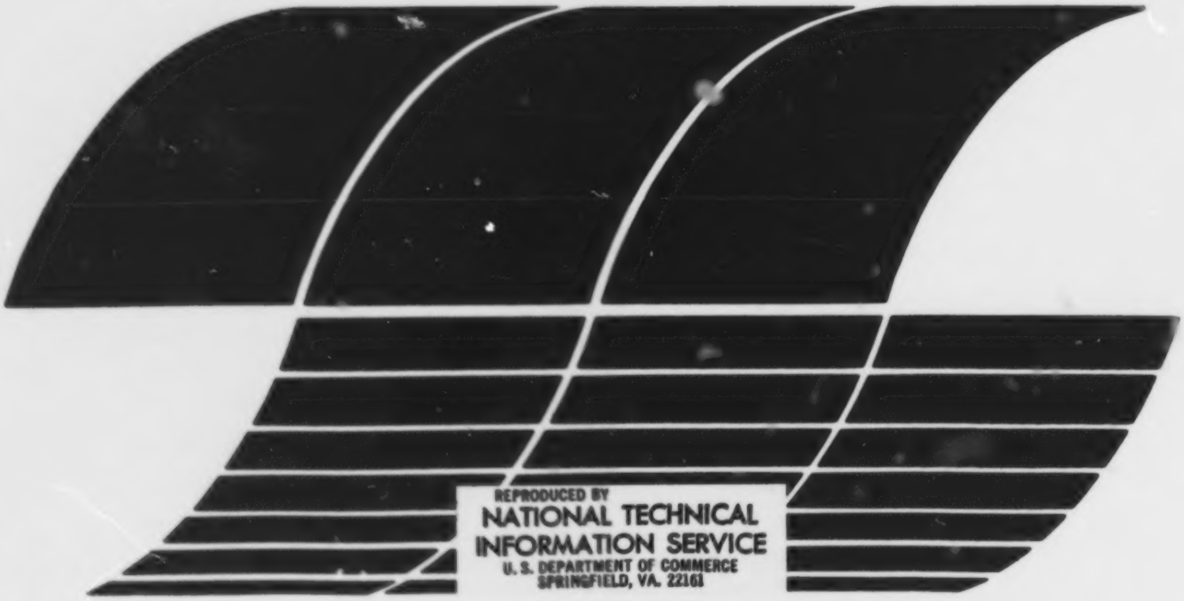

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16. ABSTRACT
The report describes a development methodology and provides sample summary sheets for a Multimedia Environmental Control Engineering Handbook. This effort is part of EPA's documentation of the environmental effects of many industrial processes (including those involving fossil fuels) to determine where environmental controls are needed and, if needed, which existing controls are applicable or may have to be developed. Each main classification of the Handbook is subdivided to specific devices or processes. The completed Handbook would require that each device have a summary sheet filled out to include appropriate identification, pollutants controlled, process description, application range, capital costs, operating costs, operating efficiencies, environmental problems, special notes, manufacturers/suppliers, and references. The completed Handbook is intended to be a reference to be used as a guide to potential solutions, and alternatives to environmental problems.

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by

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ABSTRACT

This report describes the work which has been done by Cameron Engineers, Inc. to develop the methodologies required to compile a Multimedia Environmental Control Engineering Handbook (MECEH) and to complete specific sections of the handbook. The table of contents, 88 data sheets and three examples of the secondary entry system have been completed and are contained in this report.

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INTRODUCTION

The Fuel Process Branch of the Industrial Environmental Research Laboratory, Research Triangle Park (IERL-RTP), North Carolina, is currently involved in an effort to assess the environmental effects of the fossil fuels industries, and to evaluate the control technologies necessary to meet existing and proposed standards. One goal of this effort is the compilation of a Multimedia Environmental Control Engineering Handbook (MECEH) which includes a comprehensive description of environmental control technologies applicable to fossil fuel production and use. This document would include technical information on commercially available pollution control equipment, for use by governmental agencies (federal, state, and local), environmental groups, industry, and the general public. The overall technical objectives for the handbook would be to:

- categorize all commercially available control technologies into a systematic form which will permit easy access.

- provide technical data including process descriptions, application ranges, efficiencies, and capital and operating cost information.

- compile a list of known suppliers who manufacture the specific equipment or license the technology.

This report describes the work which has been done by Cameron Engineers, Inc. to develop the methodologies required to compile the MECEH and to complete specific sections of the handbook. It is intended to show the format and content of a completed MECEH and to demonstate its usefulness when fully developed. The completion of the MECEH itself was beyond the scope of this task.

SUMMARY

The Multimedia Environmental Control Engineering Handbook will have three major sections: Table of Contents, Specific Device Data Sheets, and Secondary Entry System. A fourth section, the Index, is not included in this report. In addition, a section has been included which describes the format for the handbook and how to use it.

The table of contents divides all pollution control technologies applicable to the fossil fuels industries into nine major categories. Within each major category, further subdivisions are made, first according to generic device (a family of devices or processes having at least one distinctive feature in common) and then according to design type (a sub-family of devices or processes all based on the same physical principles). Under each design type classification is a list of specific devices or control technologies. The table of contents can be used to locate descriptions of specific equipment and to find the best available control technology when the user knows the general type of equipment which can be used to solve his problem.

The second section will be the largest section and will include a data sheet for each control technology listed in the table of contents. The data sheets will provide information on process descriptions, application ranges, capital and operating costs, operating efficiencies, environmental problems, manufacturers and additional references.

In the third section of the MECEH, the user can locate the best available control technology using only the information which he has available on the problem itself. This "Secondary Entry System", will categorize the applicable control technologies by industry, pollutant stream and pollutant species.

The final section of the MECEH will be a general index listing devices, manufacturers, specific pollutants, and other key words.

To date, the table of contents, 88 data sheets and three examples of the secondary entry system have been completed and are contained in this report.

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PURPOSE AND SCOPE OF WORK

The initial effort of this task was to develop the methodology for producing a document which could be used as a checklist by persons concerned with identifying applicable control technologies for specific pollution problems. The report was to include all industrial multimedia environmental control technologies; meaning those control technologies designed to control the release of emissions to or the degradation of air, water or land. The potential users of the document include governmental agencies, environmental groups, industry and the general public.

Several alternative organizational structures for the handbook were developed before selecting an outline and approach. The outline selected was found to give efficient access to the voluminous information which would be included in a completed Multimedia Environmental Control Engineering Handbook.

Following the development of the structure for the handbook the next major effort involved completing the table of contents. In order to accomplish this task it was necessary to perform a comprehensive review of the entire field of pollution control, accumulate information on currently used technologies, and analyze the principles of operation to develop logical classes within the table of contents. This table of contents now categorizes approximately 2,500 commercially available industrial pollution control processes or devices according to the selected classification system.

The table of contents is designed to allow a user to identify the specific device or process(es) which will control a particular pollutant provided he has a knowledge of the general (or generic) technology which is applicable. Because a particular pollution problem has in many cases more than one applicable general technology, a second means of access to the information contained in the handbook was developed.

This "secondary entry system" will allow a user to approach the MECEH from a problem oriented viewpoint. Using this system the user will evaluate his specific problem and determine the media (air, land, or water) to which

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a pollutant is discharged. Turning to the sections of the index devoted to the media of interest he can then select the industry involved and the pollutant stream of concern. The technologies which could be used for control will be listed under the pollutant stream according to the general class of pollutant. Three examples of this secondary entry system have been completed and are included in this report.

The final section of the MECEH will be a general index listing devices, manufacturers, specific pollutants, and other key words. This will allow the handbook user another means of access to the information.

FORMAT AND USE OF THE MECEH

The following will describe the four sections of the handbook and their use.

TABLE OF CONTENTS

The format for the table of contents categorizes each individual device or process according to the following system of four levels of headings.

1.0 General Classification
    1.1 Generic Device or Process
        1.1.1 Design Type
            1.1.1.1 Specific Device or Process

The first-order heading, general classification, refers to the following nine categories of pollution control technology:

1. Gas Treatment
2. Liquids Treatment
3. Solids Treatment
4. Final Disposal
5. Process Modifications
6. Combustion Modifications
7. Fuel Cleaning
8. Fugitive Emissions Control
9. Accidental Release Technology

The second level heading, the generic device or process, describes a family of specific devices or processes having at least one distinctive feature in common. For example, a group of processes may all be based upon one unit operation, or a set of specific pieces of equipment may all have similar configurations or be derived from the same general process. In these situations, the specific control devices or processes could be grouped together. Table 1 presents the generic device or process categories under each general classification which will be used within the handbook.

Each generic class is divided into third level headings of design types which group together devices which are similar in character or function and

TABLE 1

CLASSIFICATION SYSTEM FOR THE CONTROL ENGINEERING HANDBOOK

1. Gas Treatment
   - 1.1 Mechanical Collection
   - 1.2 Electrostatic Precipitators
   - 1.3 Filters (fabric, granular, etc.)
   - 1.4 Liquid Scrubbers/Contactors
   - 1.5 Condensers
   - 1.6 Solid Sorbents (mol sieves, activated carbon)
   - 1.7 Incineration (direct and catalytic)
   - 1.8 Chemical Reaction

2. Liquids Treatment
   - 2.1 Settling, Sedimentation
   - 2.2 Precipitation, Flocculation
   - 2.3 Flotation
   - 2.4 Centrifugation
   - 2.5 Filtration
   - 2.6 Evaporation and Concentration
   - 2.7 Distillation, Flashing
   - 2.8 Liquid-Liquid Extraction
   - 2.9 Gas-Liquid Stripping
   - 2.10 pH Adjustment
   - 2.11 Biological Processes
   - 2.12 Oxidation Processes
   - 2.13 Activated Carbon and Other Absorbents
   - 2.14 Ion Exchange Systems
   - 2.15 Cooling Towers and Ponds
   - 2.16 Chemical Reaction and Separation
   - 2.17 Water Intake Structures

3. Solids Treatment
   - 3.1 Fixation
   - 3.2 Recovery/Utilization
   - 3.3 Processing/Combustion
   - 3.4 Chemical Reaction and Separation
   - 3.5 Oxidation/Digestion
   - 3.6 Physical Separation (specific gravity, magnetic, etc.)

4. Final Disposal
   - 4.1 Pond Lining
   - 4.2 Deep Well Injection
   - 4.3 Burial and Landfill
   - 4.4 Sealed Contained Storage
   - 4.5 Dilution (water)
   - 4.6 Dispersion (air, land)
   - 4.7 Waste Utilization

TABLE 1 (Cont.)

5. Process Modifications
    - 5.1 Feedstock, Raw Material Changes
    - 5.2 Stream Recycle
    - 5.3 Process Improvements

6. Combustion Modifications
    - 6.1 Combustion Furnace/Burner/Process Modification
    - 6.2 Equipment Maintenance
    - 6.3 Alternate Fuels/Processes
    - 6.4 Fuel Additives/Furnace Reactants

7. Fuel Cleaning
    - 7.1 Physical Separation
    - 7.2 Chemical Refining
    - 7.3 Carbonization/Pyrolysis
    - 7.4 Treatment of Liquid Fuels
    - 7.5 Fuel Gas Treatment

8. Fugitive Emissions Control
    - 8.1 Surface Coatings/Covers
    - 8.2 Vegetation
    - 8.3 Dust Control Sprays
    - 8.4 Dust and/or Vapor Enclosures
    - 8.5 Leak Prevention
    - 8.6 Leak Detection and Repair
    - 8.7 Vent Vapor Controls
    - 8.8 Tanker Residue Control
    - 8.9 Noise Control
    - 8.10 Odor Control

9. Accidental Release Technology
    - 9.1 Spill Prevention in Storage Systems
    - 9.2 Spill Prevention in Transportation
    - 9.3 Spill Prevention in Oil & Gas Production
    - 9.4 Flares
    - 9.5 Oil Spill Barriers
    - 9.6 Oil Recovery Devices
    - 9.7 Chemical Treatment of Oil Spills
    - 9.8 Subsurface and Hazardous Spills

yet different in their basic design. An example of this is in the Fuel Cleaning Classification, where the generic device, Physical Separation, is divided into several design types, (e.g. Jigs, Launders, and Wet Concentrating Tables).

The specific device or process is the fourth level of classification and names the actual piece of equipment or the pollution control process. A single specific device sheet may encompass several different manufacturer's models which would be fundamentally the same with respect to configuration and unit operations. Devices which are significantly different in operation, efficiency, or costs will be singled out and described on a separate specific device sheet.

SPECIFIC DEVICE SHEET

Example specific device sheets are contained in a later section of this report. Each part of the sheet will be explained briefly to aid in effective use of the system. The spaces for classification, generic device or process, and specific device or process were discussed in detail under the table of contents section above.

Number

The device or process number is a coded number which gives the general classification, generic device, and design type, and numbers each specific device within the design type category. A complete device number consists of four numbers separated by decimal points.

Pollutants Controlled

This entry characterizes the pollutants which are controlled by the device or process. Pollutants are separated into four general categories (organic, inorganic, thermal, and noise). The medium or media to which the pollutant is released, and the physical form which the pollutant takes are also listed. In addition, space is provided to state the chemical formula or to give a brief technical description of the pollutant.

Process Description

Space is provided in this box for a complete process description including operating parameters, operating mechanisms, flow descriptions, materials of construction (if important), advantages, and disadvantages. It should include a description of the unique features which differentiate this specific device from all others. Schematic diagrams or photographs which better define the process are placed in the upper right corner.

Application Range

Operating limits or ranges which restrict the use of the process or device are listed in this section. Several operating parameters which are frequently of importance are listed at the right for convenience. Other parameters would include feed characteristics, feed rates, product characteristics, operating conditions which would decrease the efficiency, and external conditions which would limit the use of this process.

Capital Costs

Capital and installation cost estimates are included in this category as a function of the equipment size or throughput. The cost information will include the year for which the estimate was calculated. Data in this form can then be adjusted to current equipment cost index values and used for preliminary economic evaluations.

Operating Costs

Because operating costs are very dependent on current market prices, the operating cost information is usually presented in the form of raw material, utility and manpower requirements. Utilities include steam, electricity, water, and fuel.

Operating Efficiencies

Operating efficiencies are defined for the pollutants listed under Pollutants Controlled. Information is presented in the form of a graph or table when possible. Expected removal efficiencies for specific pollutants at different operating conditions are described over the operating range of the device or process if possible.

Environmental Problems

Environmental problems which could limit the use of the device or process will be listed here. Streams or effluents which could have a multimedia environment effect will be discussed.

Notes

Notes may be used to clarify or expand a point from the text; to cite the source of data, photographs, or information when that source is not contained in the reference section; and to provide reference to other areas or devices within the catalog. Notes are cited in the text by a capital letter superscript and listed in this section in alphabetical order according to the reference letter.

Manufacturers/Suppliers

Manufacturers and suppliers who can be contacted about licensing the process or purchasing equipment are listed alphabetically in this section. Firms will be listed by their complete name, including that for the parent company.

References

References will be used to cite the sources of data and information, and in some cases to supply the reader with a short bibliography for further investigation.

SECONDARY ENTRY SYSTEM

An outline structure for the secondary entry system is shown in Table 2. The user of the MECEH would evaluate his specific problem and determine the medium or media to which the pollutant is discharged. Turning to that section of the index he would then select the industry involved and the pollutant stream of concern. The technologies which could be used for control will be listed under the pollutant stream according to the general class of pollutant. For example, the use of this index to investigate fugitive tar emissions from a coal gasifier to a body of water indicates that dissolved toxic substances, dissolved organics, and suspended oils would be three potential water pollution problems. The best method of control would be one in which all problem areas are avoided by a single control method such as direct recycle (5.2.1). Other alternatives could include shaft seals on the tar pump (8.4.7) or collecting the spill in a catchment tank (9.1.2).

TABLE 2

SECONDARY ENTRY SYSTEM OUTLINE

- Media (air, land, water)
  - Industry
    - Pollutant Stream
      - Pollutant Species Present
        - General Technology
          - Applicable Generic Devices

INDEX

This is the final section of the handbook and will be a general index listing devices, manufacturers, specific pollutants and other key words. This will allow the user a quick means of finding a specific item of interest.

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1. GAS TREATMENT

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1.1.1.2 Sirocco Type D Collector
1.1.1.3 Van Tongeran Cyclone
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1.1.1.11 AmerClone Collector
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1.1.2 Mist Eliminators

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1.1.2.20 Type "T" Entrainment Separator
1.1.2.21 In-Line Centrifugal Entrainment Separator
1.1.2.22 Serpentine Vane Mist Eliminator
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1.1.3.6 Venturi Dust Trap
1.1.3.7 Spin Vane Separator

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1. GAS TREATMENT (Cont.)

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1.2.1.5 Needle/Plate Precipitator

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- 1.3.1.19 Pulseflo Dust Filter
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- 1.3.4.3 Dollinger Stay-New Model A Filter
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- 1.3.4.5 Thermal Dust Precipitator
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1. GAS TREATMENT (Cont.)

1.4.1 Absorption Processes (Cont.)

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1. GAS TREATMENT (Cont.)

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1.4.4.9 Secondary Flow Scrubber
1.4.4.10 Wet-Type Impingement Air Scrubber
1.4.4.11 Swemco Tray Scrubber
1.4.4.12 Bahco Scrubber

1.4.5 Orifice Type Scrubber

1.4.5.1 Blaw Knox Liquid Vortex Contactor
1.4.5.2 Circular-Wedge Scrubber
1.4.5.3 Doyle Scrubber
1.4.5.4 Schieg Swirl - Orifice Dust Collector
1.4.5.5 Type N Roto-clone
1.4.5.6 Type C Turbulaire Scrubber
1.4.5.7 Type D Turbulaire Scrubber
1.4.5.8 Zotron Wet Scrubber

1.4.6 Venturi Scrubbers

1.4.6.1 Cone Type Venturi
1.4.6.2 Damper Type Venturi
1.4.6.3 Down Flow Radial Venturi
1.4.6.4 Up Flow Radial Venturi
1.4.6.5 Dual Throat Variable Venturi
1.4.6.6 Aeromix Wet Scrubber
1.4.6.7 Airetron Venturi Scrubber
1.4.6.8 Ejector Venturi Scrubber
1.4.6.9 Flexiventuri Scrubber
1.4.6.10 Flooded-disc Venturi Scrubber
1.4.6.11 Heil Venturi Scrubber
1.6.6.12 Kinpactor Venturi Scrubber
1.4.6.13 Multiventuri Scrubber
1.4.6.14 Oriclone Venturi
1.4.6.15 Pease-Anthony Venturi Scrubber
1.4.6.16 Ventri Rod Scrubber
1.4.6.17 S-F Venturi Scrubber
1.4.6.18 Venturi-Slot Scrubber
1.4.6.19 Venturi-Sphere Scrubber
1.4.6.20 Wet Approach Venturi Scrubber
1.4.6.21 Wet-Type Venturi Air Scrubber
1.4.6.22 Stansteel Wet Type Collector
1.4.6.23 Ametek High Energy Venturi

1.4.6 Venturi Scrubbers (Cont.)

- 1.4.6.24 Ventri-Jet Low Energy
- 1.4.6.25 Horizontal Venturi
- 1.4.6.26 Pumpless Venturi
- 1.4.6.27 Multistage Venturi Spray Chamber
- 1.4.6.28 Air Pol Basic Venturi
- 1.4.6.29 Inline Wet Scrubber
- 1.4.6.30 Ducon Precooler Venturi Air Washer
- 1.4.6.31 Venturi Impactor
- 1.4.6.32 Multiple Venturi Air Washer
- 1.4.6.33 Venturi-Sorber
- 1.4.6.34 Annular Gap Scrubber
- 1.4.6.35 Ball Bed Sorber

1.4.7 Packed Columns

- 1.4.7.1 Saddle Packing
- 1.4.7.2 Flexipac
- 1.4.7.3 Raschig Ring Packing
- 1.4.7.4 Pall Ring Packing
- 1.4.7.5 Hy-Pak Ring Packing
- 1.4.7.6 Lessing Ring Packing
- 1.4.7.7 Tellerette Packing
- 1.4.7.8 Cocurrent Flow Scrubber
- 1.4.7.9 Cross Flow Scrubber
- 1.4.7.10 Fixed Bed Countercurrent Scrubber
- 1.4.7.11 Floating Bed Scrubber
- 1.4.7.12 Flooded Bed Scrubber
- 1.4.7.13 Hydro-Filter
- 1.4.7.14 Polysphere Gas Scrubber
- 1.4.7.15 Turbulent Contact Absorber
- 1.4.7.16 Freyn Spray Tower
- 1.4.7.17 Goodloe Packing
- 1.4.7.18 Panapak Packing
- 1.4.7.19 Kon-Tane Tower Packing
- 1.4.7.20 Aerosorb Gas Scrubber

1.4.8 Plate Columns

- 1.4.8.1 Counterflow Plate Columns
- 1.4.8.2 Crossflow Plate Columns
- 1.4.8.3 Split-flow Plate Columns
- 1.4.8.4 Radial Flow Plate Columns
- 1.4.8.5 Reverse Flow Plate Columns
- 1.4.8.6 Bubble Cap Tray
- 1.4.8.7 Sieve Tray
- 1.4.8.8 Nutter Tray
- 1.4.8.9 Glitch Ballast Tray
- 1.4.8.10 Turbogrid Tray
- 1.4.8.11 Perforated Tray

1. GAS TREATMENT (Cont.)

1.4.8 Plate Columns (Cont.)

- 1.4.8.12 Ripple Tray
- 1.4.8.13 Tubulent Contact Tray Scrubber

1.4.9 Wetted Wall Columns

- 1.4.9.1 Multitube Falling Film Column
- 1.4.9.2 Multitube Column with Turbulence Promoters
- 1.4.9.3 Single Tube Falling Film Column

1.4.10 Stirred Absorbers

- 1.4.10.1 Turbo-Gas-Absorber
- 1.4.10.2 Cavitator Agitated Gas Absorber
- 1.4.10.3 Turbine Agitated Tank with Sparger
- 1.4.10.4 Sparged Tank
- 1.4.10.5 Slotted Air Lift Agitated Tank
- 1.4.10.6 Porous Media Sparged Tanks
- 1.4.10.7 Propeller Agitated Tank with Sparger
- 1.4.10.8 Draft Tube Agitated Tank
- 1.4.10.9 Permaerator
- 1.4.10.10 Jet Bubbling Reactor

1.4.11 Electrostatic Scrubbers (See also Section 1.2.2)

- 1.4.11.1 Ionizing Wet Scrubber
- 1.4.11.2 Electro-Dynactor
- 1.4.11.3 Dual Charging Electrostatic Scrubber
- 1.4.11.4 Combination Electrostatic-Agglomerator Wet Scrubber
- 1.4.11.5 Electrodynamic Venturi Scrubber

1.5 Condensers

1.5.1 Direct Contact Exchanger

- 1.5.1.1 Spray Contact Condenser
- 1.5.1.2 Jet Condenser
- 1.5.1.3 Sparged Vessel Condenser

1.5.2 Indirect Contact Exchangers

- 1.5.2.1 Fined Tube Air Cooled Exchanger
- 1.5.2.2 Tube and Shell Exchanger
- 1.5.2.3 Countercurrent Spiral Heat Exchanger
- 1.5.2.4 Wet Surface Air Cooler
- 1.5.2.5 Plateflow Exchanger

1. GAS TREATMENT (Cont.)

1.6 Solid Sorbents (See also Section 7.5.4)

- 1.6.1 Adsorption Processes
    - 1.6.1.1 Anticarbone Process
    - 1.6.1.2 Alkalized Alumina Process
    - 1.6.1.3 Berghan-Forschung Process
    - 1.6.1.4 DAP-Manganese Oxide
    - 1.6.1.5 Dolomite Injection
    - 1.6.1.6 Fluidized Bed Active Carbon Process
    - 1.6.1.7 Hitachi Process
    - 1.6.1.8 Lignite Ash (Firma Carl Still)
    - 1.6.1.9 Lurgi Sulfacid Process
    - 1.6.1.10 Reinluff Process (Clean air)
    - 1.6.1.11 Pressure Swing Adsorption
    - 1.6.1.12 Purasiv HR System
    - 1.6.1.13 Ammsox Process
- 1.6.2 Adsorbent Types
    - 1.6.2.1 Active Alumina
    - 1.6.2.2 Silica Gel
    - 1.6.2.3 Zeolites
    - 1.6.2.4 Magnesia-silica Gel
    - 1.6.2.5 Carbon, shell-based
    - 1.6.2.6 Carbon, wood-based
    - 1.6.2.7 Carbon, peat-based
    - 1.6.2.8 Carbon, coal-based
    - 1.6.2.9 Carbon, petroleum-based
    - 1.6.2.10 Anhydrous Calcium Sulfate
    - 1.6.2.11 Iron Oxide
    - 1.6.2.12 Magnesia
    - 1.6.2.13 Phenolic Resin
    - 1.6.2.14 Ambersorb Carbonaceous Absorbents
- 1.6.3 Adsorption Equipment
    - 1.6.3.1 Thin/Fixed Bed Absorber
    - 1.6.3.2 Thick Bed Absorber
    - 1.6.3.3 Fluidized Bed Absorber
    - 1.6.3.4 Nonregenerative Absorber
    - 1.6.3.5 Regenerative Absorber
    - 1.6.3.6 Canister Type Absorber
    - 1.6.3.7 Corrugated Bed Type Absorber

1.7 Incineration

- 1.7.1 Direct (See also Section 9.4)
    - 1.7.1.1 Direct Flame Incinerator
    - 1.7.1.2 Nozzle Mixing Thermal Incinerator

1. GAS TREATMENT (Cont.)

1.7.1 Direct (Cont.)

1.7.1.3 Premixing Thermal Incinerator
1.7.1.4 After Burner with Energy Recovery
1.7.1.5 Thermal Regenerative System
1.7.1.6 CO Boiler
1.7.1.7 TCC Plume Burner

1.7.2 Catalytic (See also Section 7.5)

1.7.2.1 AMOCO Sulfur Recovery
1.7.2.2 Beavon Sulfur Removal Process
1.7.2.3 British Gas Council (Nicklin) Process
1.7.2.4 Catalytic Combustion Corp. Process
1.7.2.5 CBA Process (Standard)
1.7.2.6 Claus/Partial Combustion
1.7.2.7 Deoxo Process
1.7.2.8 Econ-Abator
1.7.2.9 IFP I Process
1.7.2.10 Oxycat Process
1.7.2.11 SCOT Process
1.7.2.12 Split-Stream Claus
1.7.2.13 Sulfreen (Lurgi)
1.7.2.14 Wiewiorowski Process
1.7.2.15 Purafil Odoroxidant
1.7.2.16 CO Catalytic Boiler
1.7.2.17 Interpass Absorption Process
1.7.2.18 Catalytic Fume Incineration
1.7.2.19 Catalytic Afterburner

1.8 Chemical Reaction

1.8.1 Catalytic Reduction

1.8.1.1 Catalytic Removal of NOx
1.8.1.2 High Pressure Removal of NOx
1.8.1.3 Two-Stage Reduction NOx with NH_3

1.8.2 Chemical Conversion

1.8.2.1 Kiyoura Process
1.8.2.2 Thermal DeNOx Process

2. LIQUIDS TREATMENT

2.1 Settling, Sedimentation

2.1.1 Sedimentation Tanks and Basins

2.1.1.1 Settling Channel - Manually Cleaned
2.1.1.2 Settling Channel with Traveling Rake
2.1.1.3 Settling Pond with Bucket Drag Line
2.1.1.4 Detritus Tank with Grit Washer
2.1.1.5 Aerated Grit Chamber
2.1.1.6 Batch Settling Tank
2.1.1.7 Conical Thickening Tank
2.1.1.8 Earthen-Wall Sedimentation Basin
2.1.1.9 Air-Scour Grit Chamber
2.1.1.10 Pista Grit Chamber

2.1.2 Settling Cones

2.1.2.1 Allen Settling Cone
2.1.2.2 Deep Cone Thickener
2.1.2.3 Caldecott Cone
2.1.2.4 Boylan Cone
2.1.2.5 Nordberg-Wood Classifier
2.1.2.6 Spiractor

2.1.3 Classifiers (See also Section 3.6.9)

2.1.3.1 Hardinge Hydro Classifier
2.1.3.2 Dorr Hydroseparator
2.1.3.3 Auto-Vortex Bowl Cassifier
2.1.3.4 Bowl-Rake Classifier

2.1.4 Clarifiers and Thickeners (See also Section 2.4)

2.1.4.1 Rectangular Clarifier/Chain-Type Drag
2.1.4.2 Superstructure-Supported Circular Thickener
2.1.4.3 Column - Supported Circular Thickener
2.1.4.4 Caisson Thickener
2.1.4.5 Balanced Tray Thickener
2.1.4.6 Washing Tray Thickener
2.1.4.7 Traction Thickener
2.1.4.8 Cabletorq Thickener
2.1.4.9 Square Clarifier with Circular Rake
2.1.4.10 Rectangular Traveling Bridge Clarifier
2.1.4.11 Floating Bridge Clarifiers
2.1.4.12 Combined Primary and Secondary Sedimentation Tank
2.1.4.13 Thixo Arm Thickener
2.1.4.14 Reactor Clarifier
2.1.4.15 Hopper Sludge Removal
2.1.4.16 Hydrostatic Sludge Removal
2.1.4.17 Vacuum Sludge Removal

2. LIQUIDS TREATMENT (Cont.)

2.1.4 Clarifiers and Thickners (Cont.)

- 2.1.4.18 Rim Feed Clarifier
- 2.1.4.19 Two Stage Split Flow Clarifier
- 2.1.4.20 Sludge Blanket Clarifier
- 2.1.4.21 Solids Contact Unit
- 2.1.4.22 Upflow Basin
- 2.1.4.23 Hydro-Circ Flow Clarifier
- 2.1.4.24 Square Cross Flow Clarifier
- 2.1.4.25 Permutit Horizontal Precipitator
- 2.1.4.26 ClariFlow Clarifier
- 2.1.4.27 Degritting Clarifier
- 2.1.4.28 Duo Clarifier

2.1.5 Tilted Tube and Plate Settlers

- 2.1.5.1 Lamella Gravity Settler
- 2.1.5.2 60° Tube Settler
- 2.1.5.3 7-1/2° Tube Settler
- 2.1.5.4 Settlex Clarifier
- 2.1.5.5 Corrugated Plate Sediment Separator
- 2.1.5.6 Cross-Flow Corrugated Plate Separator
- 2.1.5.7 Chevron Tube System
- 2.1.5.8 Linatex-Serpac Process

2.1.6 Oil Skimmers

- 2.1.6.1 Absorbent Belt Skimmer
- 2.1.6.2 Absorbent Drum Skimmer
- 2.1.6.3 Adsorbent Rope Skimmer
- 2.1.6.4 Adsorbent Belt Skimmer
- 2.1.6.5 Adsorbent Drum Skimmer
- 2.1.6.6 Air Jet Skimmer
- 2.1.6.7 Chain and Flight Skimmer
- 2.1.6.8 Fixed Floating Weir Skimmer
- 2.1.6.9 Floating Tube Skimmer
- 2.1.6.10 Free Floating Weir Skimmer
- 2.1.6.11 Radial Arm Skimmer
- 2.1.6.12 Rotating Disc Skimmer
- 2.1.6.13 Slotted Pipe Skimmer
- 2.1.6.14 Spiral Skimmer
- 2.1.6.15 Suction Type Skimmer
- 2.1.6.16 Traveling Bridge Skimmer
- 2.1.6.17 Vortex Skimmer

2.1.7 Oil-Water Separators (Also See 2.1.5)

- 2.1.7.1 API Separator
- 2.1.7.2 Circular Settling Basin
- 2.1.7.3 Rectangular Settling Basin
- 2.1.7.4 Wash Tanks & Skim Tanks

2. LIQUID TREATMENT (Cont.)

2.1.7 Oil-Water Separators (Cont.)

2.1.7.5 Horizontal Decanter
2.1.7.6 Gravity Displacement Separator
2.1.7.7 Parallel Plate Interceptor
2.1.7.8 Corrugated Plate Interceptor
2.1.7.9 Vertical Tube Coalescer
2.1.7.10 Fibrous Media Coalescer
2.1.7.11 Loose Media Coalescer
2.1.7.12 Horizontal Plate Coalescer

2.2 Precipitation, Flocculation

2.2.1 Chemical Precipitation (See also Section 2.10)

2.2.1.1 Sulfide
2.2.1.2 Cementation
2.2.1.3 Hydroxide
2.2.1.4 Sulfuric Acid
2.2.1.5 Dolomite
2.2.1.6 Ventron Process
2.2.1.7 Sulfur Dioxide
2.2.1.8 Soda Ash
2.2.1.9 Calcium Chloride
2.2.1.10 Ferrous Sulfate
2.2.1.11 Sodium Metabisulfite
2.2.1.12 Sulfex Process

2.2.2 Chemical Coagulants (See also Section 5.2.2)

2.2.2.1 Aluminum Salts
2.2.2.2 Lime
2.2.2.3 Iron Salts
2.2.2.4 Hot Lime Process
2.2.2.5 Magnesium Oxide
2.2.2.6 Lanthanum Salts

2.2.3 Polyelectrolyte Flocculants

2.2.3.1 Anionic
2.2.3.2 Cationic
2.2.3.3 Nonionic
2.2.3.4 Variable Charge

2.2.4 Coagulant Aids

2.2.4.1 Sodium Silicate
2.2.4.2 Bentonite Clay
2.2.4.3 Activated Silica
2.2.4.4 Fly Ash

2. LIQUID TREATMENT (Cont.)

- 2.2.4 Coalgulant Aids
  - 2.2.4.5 Recycled Sludge
  - 2.2.4.6 Foam Control Agents
- 2.2.5 Demulsifying Processes (See also Section 2.2.2 and 2.2.3)
  - 2.2.5.1 Magnesium Chloride
  - 2.2.5.2 Acid Treatment
  - 2.2.5.3 Regular Demulsifiers
  - 2.2.5.4 Reverse Demulsifiers
  - 2.2.5.5 Sodium Carbonate
  - 2.2.5.6 Calcium Chloride
  - 2.2.5.7 Alkali Treatment
  - 2.2.5.8 Heat Treatment
  - 2.2.5.9 Distillation
  - 2.2.5.10 Electrical Methods
  - 2.2.5.11 Oil Addition
  - 2.2.5.12 Hollow Fiber Demulsifier
- 2.2.6 Paddle Flocculators
  - 2.2.6.1 Horizontal Paddle Flocculator
  - 2.2.6.2 Inclined Paddle Flocculator
  - 2.2.6.3 Vertical Paddle Flocculator
  - 2.2.6.4 Horizontal Paddle Oscillating Flocculator
  - 2.2.6.5 Tandem Paddle Slow Mixer
- 2.2.7 Turbine Flocculators
  - 2.2.7.1 Draft Tube Turbine Flocculator
  - 2.2.7.2 Vertical Turbine Flocculator
  - 2.2.7.3 Horizontal Turbine Flocculator
  - 2.2.7.4 Slow-Speed Axial Flow Turbine Flocculator
- 2.2.8 Miscellaneous Flocculators
  - 2.2.8.1 Corrugated Plate Flocculator
  - 2.2.8.2 Air Flocculator
  - 2.2.8.3 Magnetic Flocculator
  - 2.2.8.4 Feed Wells with Inboard Weir Troughs

2.3 Flotation (See also Section 3.6.3 and 7.1.6)

- 2.3.1 Mechanical Subaeration Cells
  - 2.3.1.1 Fagergren Level - Type Machine
  - 2.3.1.2 WEMCO Hydrocleaner
  - 2.3.1.3 Fagergren Oblong - Type Machine
  - 2.3.1.4 UIW Machine
  - 2.3.1.5 Pan American Machine
  - 2.3.1.6 MS Subaeration Machine

2. LIQUID TREATMENT (Cont.)

2.3.1 Mechanical Subaeration Cells

- 2.3.1.7 MS Countercurrent Machine
- 2.3.1.8 Geco Machine
- 2.3.1.9 Weinig Machine
- 2.3.1.10 Hall Deep Cell
- 2.3.1.11 Janney Mechanical Machine
- 2.3.1.12 Mechanical/Honeycomb Baffel Tank
- 2.3.1.13 Quadricell Separator

2.3.2 Pneumatic Cells

- 2.3.2.1 Foam Fractionation Unit
- 2.3.2.2 Callow Cell
- 2.3.2.3 MacIntosh Cell
- 2.3.2.4 Forrester Cell
- 2.3.2.5 Hunt Cell
- 2.3.2.6 Welsh Cell
- 2.3.2.7 Emery Cell
- 2.3.2.8 Deep Air Cell
- 2.3.2.9 WEMCO Depurator Flotation Machine
- 2.3.2.10 Aero-flo Sparger

2.3.3 Dissolved Air Units

- 2.3.3.1 Total Pressurization
- 2.3.3.2 Partial Pressurization
- 2.3.3.3 Recycle Pressurization
- 2.3.3.4 Circular Flotation Tank with Rake
- 2.3.3.5 IR Countercurrent Flotation Separator
- 2.3.3.6 Pielkenroad DAF System
- 2.3.3.7 Rectangular Flotation Tank with Skimmer
- 2.3.3.8 Vacuum Flotation
- 2.3.3.9 Potter-Delprat Process
- 2.3.3.10 Agitation-Froth Machine
- 2.3.3.11 Mineral Separation Machine
- 2.3.3.12 Positive Air Dissolution System
- 2.3.3.13 Jupiter-7000 System

2.3.4 Flotation Conditioners (See also Section 2.2)

- 2.3.4.1 Frothers
- 2.3.4.2 Promoters
- 2.3.4.3 Modifiers

2.4 Centrifugation

2.4.1 Hydrocyclones

- 2.4.1.1 "Fine Mixer" Cyclone
- 2.4.1.2 Hydrocyclone
- 2.4.1.3 Classifying Cyclone
- 2.4.1.4 WEMCO Cyclonic Grit Separator & Washer

2. LIQUID TREATMENT (Cont.)

2.4.1 Hydrocyclones (Cont.)

- 2.4.1.5 Laval Separator
- 2.4.1.6 Dorrclone Separator
- 2.4.1.7 Multiple Cyclone Systems
- 2.4.1.8 Automatic Discharge Cyclones

2.4.2 Basket Centrifuges

- 2.4.2.1 Carpenter Centrifugal Filter
- 2.4.2.2 Base-Bearing Centrifugal
- 2.4.2.3 Link-Suspended Batch Centrifugal
- 2.4.2.4 Top Suspended Centrifugal
- 2.4.2.5 Automatic Batch Horizontal Centrifugal
- 2.4.2.6 Horizontal Screen-Conveyor Centrifuge
- 2.4.2.7 Wide-Angle Conical Screen Centrifugal
- 2.4.2.8 Vertical Conveyor Centrifuge
- 2.4.2.9 Reciprocating Pusher Multi-Stage
- 2.4.2.10 Reciprocating Pusher Single Stage
- 2.4.2.11 Conical Screen with Differential Conveyor
- 2.4.2.12 Vibrating Conical Horizontal Screen
- 2.4.2.13 Vibrating Conical Vertical Screen
- 2.4.2.14 Reciprocating Pusher Conical Screen
- 2.4.2.15 Conical Basket Slip Discharge
- 2.4.2.16 Broadbent Conical Bowl Continuous
- 2.4.2.17 Conical Basket Torsional Vibratory Discharge
- 2.4.2.18 Mercone Screening Centrifuge

2.4.3 Solid Bowl Centrifuges

- 2.4.3.1 Top-Suspended Knife Discharge
- 2.4.3.2 Horizontal Bowl Knife Discharge
- 2.4.3.3 Base-Bearing Manual Discharge
- 2.4.3.4 Cocurrent Solid Bowl Conveyor
- 2.4.3.5 Two-Stage Solid Bowl Operation
- 2.4.3.6 Multi-Chamber Centrifuge
- 2.4.3.7 Tubular-Bowl High Speed Centrifuge
- 2.4.3.8 Helical-Conveyor Cylindrical Bowl
- 2.4.3.9 Helical-Conveyor Cylindrical-Conical Bowl
- 2.4.3.10 Podbielniak Centrifugal Contactor
- 2.4.3.11 Turbo-Flite Solid Bowl
- 2.4.3.12 Solid Bowl/Screen Sedimenter
- 2.4.3.13 Vortex Clarifier
- 2.4.3.14 Vertical Helical-Conveyor Cylindrical Bowl
- 2.4.3.15 Roto-Filter Pump

2.4.4 Disc Centrifuges

- 2.4.4.1 Top Suspended Disc
- 2.4.4.2 Bottom Supported Disc
- 2.4.4.3 Manual Discharge with Centripetal Pump
- 2.4.4.4 Hermetic Centrifuge

2. LIQUID TREATMENT (Cont.)

2.4.4 Disc Centrifuges (Cont.)

- 2.4.4.5 Nozzel Discharge
- 2.4.4.6 Nozzel Discharge with Recirculation
- 2.4.4.7 Valve Discharge
- 2.4.4.8 Peripheral-Annulus Discharge
- 2.4.4.9 Light Phase Skimmer
- 2.4.4.10 Double Overflow

2.5 Filtration

2.5.1 Bar Screens

- 2.5.1.1 Hand Cleaned Bar Rack
- 2.5.1.2 Frontcleaned Flat Bar Rack
- 2.5.1.3 Backcleaned Flat Bar Rack
- 2.5.1.4 Mechanically Cleaned Curved Bar Screen
- 2.5.1.5 Mechanical Bar Screen with Grit Collection
- 2.5.1.6 Tritor Screen
- 2.5.1.7 Transversing Trash Screen

2.5.2 Comminuting Screens

- 2.5.2.1 Hammer Mill Screening Grinder
- 2.5.2.2 Shredder Type Screening Grinder
- 2.5.2.3 Rotating Screen Comminutor
- 2.5.2.4 Rotating Cutter Comminutor
- 2.5.2.5 Oscillating Cutter Comminutor
- 2.5.2.6 Barminutor
- 2.5.2.7 Macerator
- 2.5.2.8 Flominutor

2.5.3 Vibratory Screens

- 2.5.3.1 Shaker Screen
- 2.5.3.2 Vibrating Screen
- 2.5.3.3 Gyratory Screen

2.5.4 Rotary Screens

- 2.5.4.1 Revolving Drum with Inward Flow
- 2.5.4.2 Revolving Drum with Outward Flow
- 2.5.4.3 Revolving Vertical Disk
- 2.5.4.4 Inclined Revolving Disk
- 2.5.4.5 Vertical Drum
- 2.5.4.6 Internal Helix Rotary Drum Screen
- 2.5.4.7 Revolving Disc Screen
- 2.5.4.8 Merco Rotary Strainer
- 2.5.4.9 Batam Strainer

2. LIQUID TREATMENT (Cont.)

- 2.5.5 Microscreens
  - 2.5.5.1 Revolving Drum
  - 2.5.5.2 Stationary Backwash Filter Screens
  - 2.5.5.3 Cartridge Type Stationary Filter Screens
  - 2.5.5.4 Rotary Brush Microstrainer
  - 2.5.5.5 Porous Metal Cartridge Filter
  - 2.5.5.6 Traveling Water Screen
  - 2.5.5.7 Dual Flow Traveling Water Screen
- 2.5.6 Other Screens
  - 2.5.6.1 Coarse Mesh Screen
  - 2.5.6.2 Traveling Water Screen
  - 2.5.6.3 Endless Band Screen
  - 2.5.6.4 Hydrasieve
  - 2.5.6.5 WEMCO Rotary Sieve
  - 2.5.6.6 Static Multiple Angle Screen
  - 2.5.6.7 Vor-Siv
  - 2.5.6.8 120°DSM Screen
  - 2.5.6.9 300°DSM Screen
  - 2.5.6.10 AES 3600 Strainer
- 2.5.7 Bag Filters
  - 2.5.7.1 Gravity Bag Filter
  - 2.5.7.2 Pressure Bag Filter
  - 2.5.7.3 End of Pipe Bag Filter
- 2.5.8 Cartridge Filters
  - 2.5.8.1 Edge Filter
  - 2.5.8.2 Wound Wire Filter
  - 2.5.8.3 Cuno Flo-Klean Filter
  - 2.5.8.4 Cuno Auto-Klean Filter
  - 2.5.8.5 Fiber Cartridge
  - 2.5.8.6 Resin-Impregnated Filter Paper
  - 2.5.8.7 Porous Stone
  - 2.5.8.8 Packed Cartridge Filters
  - 2.5.8.9 Backflush Annular Filter
  - 2.5.8.10 Regenerative DE Filter
  - 2.5.8.11 Lined Tubular Filter
- 2.5.9 Granular Bed Filters
  - 2.5.9.1 Deep Bed with Intermittent Backwash
  - 2.5.9.2 Ground Level Outdoor Granular Bed
  - 2.5.9.3 Closed Tank Deep Bed
  - 2.5.9.4 Dual Layer Granular Bed
  - 2.5.9.5 Anthracite Filters
  - 2.5.9.6 Rapid Sand Filters

2. LIQUID TREATMENT (Cont.)

2.5.9 Granular Bed Filters

- 2.5.9.7 Slow Sand Filters
- 2.5.9.8 Multiple Layer with Air Scouring
- 2.5.9.9 Ultra-High Rate Filter
- 2.5.9.10 Moving Bed Filter
- 2.5.9.11 Mixed Media Filter
- 2.5.9.12 Upflow Filter
- 2.5.9.13 Dual-Flow Filter
- 2.5.9.14 Radial Flow Filter
- 2.5.9.15 Horizontal Pressure Granular Filter
- 2.5.9.16 Vertical Pressure Granular Filter
- 2.5.9.17 Hardinge Super Thickener
- 2.5.9.18 Automatic Valveless Backwash Filter
- 2.5.9.19 Hydro-Clear Filter Cell
- 2.5.9.20 Traveling Bridge Granular Filter
- 2.5.9.21 Mono-Pak Filter
- 2.5.9.22 Activated Carbon Filter
- 2.5.9.23 Intermittent Sand Filter
- 2.5.9.24 Electro-Filter Separator
- 2.5.9.25 Monovalve Automatic Gravity Filter

2.5.10 Leaf Filters

- 2.5.10.1 Kelly Filter
- 2.5.10.2 Sweetland Filter
- 2.5.10.3 Vallez Filter
- 2.5.10.4 Horizontal Pressure Leaf with Sluice Discharge
- 2.5.10.5 Horizontal Leaf with Retractable Rack
- 2.5.10.6 Vertical Pressure Leaf
- 2.5.10.7 Moore Filter
- 2.5.10.8 Genter Filter Thickener
- 2.5.10.9 Artisan Horizontal Continuous Pressure Filter

2.5.11 Tubular Filters

- 2.5.11.1 Vertical Pressure Tube Filter
- 2.5.11.2 Industrial Tubular Filter
- 2.5.11.3 Ultra-Kleen Regenerative DE Filter

2.5.12 Filter Presses

- 2.5.12.1 Automatic Cleaning Filter Press
- 2.5.12.2 Plate and Frame Filter
- 2.5.12.3 Recessed-Plate Filter
- 2.5.12.4 Roll-Over Plate and Frame
- 2.5.12.5 Simple Wash Filter
- 2.5.12.6 Thorough Wash Filter
- 2.5.12.7 Carver Hydraulic Filter Press
- 2.5.12.8 Eimco-Burwell Filter
- 2.5.12.9 Granger Filter

2. LIQUID TREATMENT (Cont.)

2.5.12 Filter Presses (Cont.)

- 2.5.12.10 Readco Short-Cycle Filter
- 2.5.12.11 Shriver Continuous Thickener
- 2.5.12.12 Sheet Filter
- 2.5.12.13 Merril Press
- 2.5.12.14 Center Filling Press
- 2.5.12.15 Screw Press
- 2.5.12.16 Disc Press
- 2.5.12.17 Tank Enclosed Filter Press
- 2.5.12.18 Two Stage Filter Press
- 2.5.12.19 Tube Filter Press
- 2.5.12.20 Magnum Press
- 2.5.12.21 Flocpress
- 2.5.12.22 Multi-Roll Sludge Dewatering Press
- 2.5.12.23 Vari-Nip Twin-Roll Press

2.5.13 Disc Filters

- 2.5.13.1 Vertical Disc
- 2.5.13.2 Horizontal Disc
- 2.5.13.3 Pressure-Type Disc Filter
- 2.5.13.4 Peterson Roto-Disc Clarifier
- 2.5.13.5 Disk Clarifying Filter

2.5.14 Drum Filters

- 2.5.14.1 Top Feed
- 2.5.14.2 Scraper Discharge
- 2.5.14.3 Belt with Helical Discharge Roll
- 2.5.14.4 String Discharge
- 2.5.14.5 Roll Discharge
- 2.5.14.6 Heated-Belt Discharge
- 2.5.14.7 Coil-Type Filter
- 2.5.14.8 Precoat Filter with Advancing Knife
- 2.5.14.9 Internal Feed
- 2.5.14.10 Single Compartment Vacuum Drum
- 2.5.14.11 Roto-Plug Thickener
- 2.5.14.12 Compression Filter
- 2.5.14.13 Burt Filter
- 2.5.14.14 Continuous Pressure Drum Filter
- 2.5.14.15 Rotary Hopper Dewaterer
- 2.5.14.16 Permutit DCG Sludge Dewatering Unit

2.5.15 Horizontal Filters

- 2.5.15.1 Gravity Nutsche
- 2.5.15.2 Pressure Nutsche
- 2.5.15.3 Vacuum Nutsche
- 2.5.15.4 Batch Pan Filter
- 2.5.15.5 Horizontal Plate Filter
- 2.5.15.6 Rodney Hunt Pressure Filter

2. LIQUID TREATMENT (Cont.)

2.5.15 Horizontal Filters (Cont.)

- 2.5.15.7 Horizontal Table Filter
- 2.5.15.8 Tilting Pan Filter
- 2.5.15.9 Continuous Vacuum Belt
- 2.5.15.10 Delpark Industrial Filter
- 2.5.15.11 Disk and Plate Clarifying Filter
- 2.5.15.12 Pulp Filter
- 2.5.15.13 Caldecott Table
- 2.5.15.14 Disposable Paper Filter
- 2.5.15.15 Vacu-Matic Filter

2.5.16 Filtration Processes

- 2.5.16.1 Magnetic Filter
- 2.5.16.2 Magnetic Trap
- 2.5.16.3 Thermal Conditioning Filtration
- 2.5.16.4 Porteous Process
- 2.5.16.5 Chemical Conditioning Filtration
- 2.5.16.6 Elutriation
- 2.5.16.7 Basic Extractive Sludge Treatment

2.5.17 Ultrafiltration

- 2.5.17.1 Plate-Type Ultrafilter
- 2.5.17.2 Tube-Type Ultrafilter
- 2.5.17.3 Hollow Fiber Ultrafilter
- 2.5.17.4 Spiral-Wound Unit

2.5.18 Reverse Osmosis (Hyperfiltration)

- 2.5.18.1 Tube-Type Unit
- 2.5.18.2 Spiral-Wound Unit
- 2.5.18.3 Hollow Filament Unit
- 2.5.18.4 Plate and Frame Unit
- 2.5.18.5 Shell and Tube-Type Unit
- 2.5.18.6 Dynamically Formed Membrane

2.5.19 Electrodialysis

- 2.5.19.1 Staged Continuous Unit
- 2.5.19.2 Parallel Continuous Units
- 2.5.19.3 Batch Recirculation Process
- 2.5.19.4 Feed and Bleed Process
- 2.5.19.5 Internally Staged Process
- 2.5.19.6 Anionic Membranes
- 2.5.19.7 Cationic Membranes

2.6 Evaporation and Concentration

2.6.1 Ponds and Lagoons (See also Section 4.1)

- 2.6.1.1 Solar Heated Ponds
- 2.6.1.2 Externally Heated Ponds

2. LIQUID TREATMENT (Cont.)

2.6.2 Heated Tanks and Vessels

- 2.6.2.1 Jacket Kettles
- 2.6.2.2 Tanks with Coiled Tubes
- 2.6.2.3 Channel-Switching Evaporator
- 2.6.2.4 Tank with Flat Plat Exchanger
- 2.6.2.5 Submerged Combustion Evaporation
- 2.6.2.6 Rotating Disc Evaporator
- 2.6.2.7 Cascade Evaporation
- 2.6.2.8 Direct Heat Transfer with Immisible Liquid
- 2.6.2.9 Porcupine Processor

2.6.3 Spray Evaporators

- 2.6.3.1 Horizontal Spray Chamber
- 2.6.3.2 Vertical Direct Contact Chamber
- 2.6.3.3 Vertical Indirect Heating Chamber
- 2.6.3.4 Pressure Nozzle Spray Dryer
- 2.6.3.5 Two-Fluid Nozzle Spray Dryer
- 2.6.3.6 Centrifugal Disk Spray Dryer
- 2.6.3.7 Centrifugal Spray Dryer

2.6.4 Tubular Evaporators

- 2.6.4.1 Horizontal Fire Tube Evaporator
- 2.6.4.2 Horizontal Steam Tube Evaporator
- 2.6.4.3 Forced Circulation Evaporator
- 2.6.4.4 Oslo-Type Crystallizer
- 2.6.4.5 Short Tube Vertical Evaporator
- 2.6.4.6 Propeller Calandria
- 2.6.4.7 Long-Tube Vertical Evaporator
- 2.6.4.8 Recirculating Long Tube Vertical Evaporator
- 2.6.4.9 Bent-Tube Horizontal Evaporator
- 2.6.4.10 Artisan Multi-Stage Evaporator
- 2.6.4.11 Artisan Continuous Evaporator

2.6.5 Film Type Evaporators

- 2.6.5.1 Falling-Film Long Tube Vertical Evaporator
- 2.6.5.2 Rising-Film Long Tube Vertical Evaporator
- 2.6.5.3 Agitated Film Evaporator
- 2.6.5.4 Rototherm Thin-Film Evaporator
- 2.6.5.5 Pfandler Wiped-Film Evaporator
- 2.6.5.6 Aqua Chem Spray Film Evaporator
- 2.6.5.7 Rising/Falling Film Tubular Evaporator
- 2.6.5.8 Rising/Falling Film Plate Evaporator
- 2.6.5.9 Falling Film Plate Evaporator
- 2.6.5.10 ParaVap Evaporator

2.6.6 Evaporation Processes

- 2.6.6.1 Mechanical Thermocoupression Heating
- 2.6.6.2 Secondary Fluid Thermocompression Heating

2. LIQUID TREATMENT (Cont.)

2.6.6 Evaporation Processes (Cont.)

- 2.6.6.3 Steam Jet Thermocompression Heating
- 2.6.6.4 Backward-Feed Multiple Effect Evaporation
- 2.6.6.5 Forward-Feed Multiple Effect Evaporation
- 2.6.6.6 Parallel-Feed Multiple Effect Evaporation
- 2.6.6.7 Vacuum Evaporation
- 2.6.6.8 Vapor Reheat Process

2.6.7 Freeze Concentration

- 2.6.7.1 Single Stage Freeze Process
- 2.6.7.2 Zarchin-Colt Process
- 2.6.7.3 Indirect Contact Freezing Process
- 2.6.7.4 Direct Contact Freezing Process
- 2.6.7.5 Hydrate Process
- 2.6.7.6 Vacuum Freezing/Vapor Recompression Process
- 2.6.7.7 Pressure Freezing Process

2.7 Distillation and Flashing

2.7.1 Plate Type Distillation Columns (See Section 1.4.8)

2.7.2 Packed Tower Distillation Columns (See Section 1.4.7)

2.7.3 Molecular Distillation

- 2.7.3.1 Molecular Distillation

2.7.4 Flash Vaporization

- 2.7.4.1 Submerged Tube Forced Circulation Evaporation
- 2.7.4.2 Single Effect Multistage Flash Evaporation
- 2.7.4.3 Multiple Effect Flash Evaporation
- 2.7.4.4 Combined Vertical Tube/Multistage Flash Evaporation
- 2.7.4.5 Flash Enhancers
- 2.7.4.6 Foul Water Vaporization in Cracking Units

2.8 Liquid-Liquid Extraction

2.8.1 Extraction Processes

- 2.8.1.1 Jones & Laughlin
- 2.8.1.2 Phenosolvan
- 2.8.1.3 Phenolics Extractions in Crude Oil Desalter
- 2.8.1.4 Koppers Light Oil Extraction
- 2.8.1.5 Chemizon
- 2.8.1.6 Barrett
- 2.8.1.7 Phenex
- 2.8.1.8 Benzene-Caustic
- 2.8.1.9 Ifawol
- 2.8.1.10 Pott-Hilgenstock
- 2.8.1.11 Tricresy Phosphate ("Triphos")

2. LIQUID TREATMENT (Cont.)

2.8.1 Extraction Processes (Cont.)

- 2.8.1.12 Holley-Mott
- 2.8.1.13 Lowenstein-Lom
- 2.8.1.14 Basic Extractive Sludge Treatment

2.8.2 Mixer-Settlers

- 2.8.2.1 Jet Mixer
- 2.8.2.2 Injectors
- 2.8.2.3 Orifice Nozzle
- 2.8.2.4 Mixing Nozzle
- 2.8.2.5 Valve
- 2.8.2.6 Pumps
- 2.8.2.7 Agitated Line Mixers
- 2.8.2.8 Baffled Mixing Vessel
- 2.8.2.9 Unbaffled Mixing Vessel
- 2.8.2.10 Multicompartment Agitated Vessel
- 2.8.2.11 Pump-Mix Extractor
- 2.8.2.12 Kerr-McGee Multistage Mixer Settler
- 2.8.2.13 Five Stage Countercurrent Cascade Extractor
- 2.8.2.14 Vitro Mixer Settler
- 2.8.2.15 Windscale
- 2.8.2.16 General Mills
- 2.8.2.17 Davy Powergas
- 2.8.2.18 IMI
- 2.8.2.19 Kemira
- 2.8.2.20 Lurgi Horizontal
- 2.8.2.21 Lurgi Vertical
- 2.8.2.22 Holmes & Narver

2.8.3 Differential Contact Gravity Columns (See also Section 1.4.7)

- 2.8.3.1 Elgin-End Spray Tower
- 2.8.3.2 Raschig Rings
- 2.8.3.3 Berl Saddles
- 2.8.3.4 Intalox Saddles
- 2.8.3.5 Knit Cloth Packing
- 2.8.3.6 Bead Packing
- 2.8.3.7 Wooden Hurdles
- 2.8.3.8 Pall Rings

2.8.4 Staged Contact Gravity Columns (See also Section 1.4.8)

- 2.8.4.1 Sieve-Plate Columns
- 2.8.4.2 Koch Tray Column
- 2.8.4.3 Perforated Plant Column
- 2.8.4.4 Bubble Cap Tower
- 2.8.4.5 Disc and Doughnut Baffle Tower
- 2.8.4.6 Center to Side Baffle Tower

2. LIQUID TREATMENT (Cont.)

2.8.5 Mechanically Agitated Contactors

- 2.8.5.1 Rotary Annular Column
- 2.8.5.2 Multistage Mixer Column
- 2.8.5.3 Rotating-Disk Contactor
- 2.8.5.4 Rotating-Core Column
- 2.8.5.5 Mixco Column
- 2.8.5.6 Scheibel Column
- 2.8.5.7 Oldshue-Rushton Column
- 2.8.5.8 Luhni Column
- 2.8.5.9 Asymmetric Rotating Disc Extractor
- 2.8.5.10 Graesser Contactor
- 2.8.5.11 Horizontal Pipeline Extractor

2.8.6 Centrifugal Extractors

- 2.8.6.1 Podbielniak
- 2.8.6.2 Quadronic
- 2.8.6.3 Westfalia
- 2.8.6.4 De Laval
- 2.8.6.5 Robatel
- 2.8.6.6 Luwesta

2.9 Gas-Liquid Stripping

2.9.1 Stripping Processes

- 2.9.1.1 Vacuum Stripping
- 2.9.1.2 Non-Refluxed Steam Stripping
- 2.9.1.3 Refluxed Steam Stripping
- 2.9.1.4 WTT Process
- 2.9.1.5 Combined Spent Caustic/Foul Water Stripping
- 2.9.1.6 Flue Gas Stripping

2.9.2 Stripping Equipment

- 2.9.2.1 Cooling Towers
- 2.9.2.2 Packed Columns (See Section 1.4.7)
- 2.9.2.3 Spray Columns
- 2.9.2.4 Plate Columns (See Section 1.4.8)
- 2.9.2.5 Wetted Wall Columns (See Section 1.4.9)
- 2.9.2.6 Spargers
- 2.9.2.7 Reboiler Type Stripper
- 2.9.2.8 Artisan Continuous Stripper

2.10 pH Adjustment

2.10.1 Neutralization with Acids

- 2.10.1.1 Sulfuric Acid
- 2.10.1.2 Hydrochloric Acid
- 2.10.1.3 Carbon Dioxide

2. LIQUID TREATMENT (Cont.)

- 2.10.1 Neutralization with Acids
  - 2.10.1.4 Sulfur Dioxide
  - 2.10.1.5 Nitric Acid
- 2.10.2 Neutralization with Bases
  - 2.10.2.1 Caustic Soda
  - 2.10.2.2 Ammonia
  - 2.10.2.3 Soda Ash
  - 2.10.2.4 Hydrated Lime
  - 2.10.2.5 Limestone
- 2.10.3 Buffering
  - 2.10.3.1 Buffering
- 2.10.4 pH Adjustment Equipment
  - 2.10.4.1 Two Stage Tank
  - 2.10.4.2 Mixmeter

2.11 Biological Processes

- 2.11.1 Anaerobic (See also Section 3.5.2)
  - 2.11.1.1 Anaerobic Lagoon
  - 2.11.1.2 Raw Sewage Facultative Lagoon
  - 2.11.1.3 Multipond Facultative Lagoon
  - 2.11.1.4 Anaerobic-Aerobic Pond System
  - 2.11.1.5 Denitrification
- 2.11.2 Activated Sludge
  - 2.11.2.1 Plug Flow Conventional Process
  - 2.11.2.2 Extended Aeration Process
  - 2.11.2.3 High Rate Process
  - 2.11.2.4 Nitrification Process
  - 2.11.2.5 Two-Stage Nitrification Process
  - 2.11.2.6 Spiral Flow Conventional Process
  - 2.11.2.7 Step Aeration Process
  - 2.11.2.8 Two-Stage Contact Stabilization
  - 2.11.2.9 Completely Mixed Process
  - 2.11.2.10 Pure Oxygen Surface Aeration System
  - 2.11.2.11 Pure Oxygen Sparger System
  - 2.11.2.12 Tapered Aeration System
  - 2.11.2.13 Pure Oxygen Nitrification
  - 2.11.2.14 Kraus Process
  - 2.11.2.15 Modified Aeration Process
  - 2.11.2.16 Unox System
  - 2.11.2.17 Simplex Oxygenation System
  - 2.11.2.18 Zurn-Attisholz Two-Stage Process

2. LIQUID TREATMENT (Cont.)

2.11.2 Activated Sludge (Cont.)

- 2.11.2.19 Claraetor
- 2.11.2.20 Spirovortex System
- 2.11.2.21 Modular Prestressed Concrete Wastewater Plant
- 2.11.2.22 Combined Settling Continuous Activated Sludge System

2.11.3 Aerated Lagoons and Ditches

- 2.11.3.1 Synthetically Lined Aerobic Lagoon
- 2.11.3.2 Riprap Lined Aerobic Lagoon
- 2.11.3.3 Mechanically Aerated Oxidation Ponds
- 2.11.3.4 Single Oxidation Ditch
- 2.11.3.5 Multiple Oxidation Ditch

2.11.4 Trickling Filters

- 2.11.4.1 Rock Media
- 2.11.4.2 Aeroblock Media
- 2.11.4.3 Ring-Type Media
- 2.11.4.4 Dowpac Media
- 2.11.4.5 Surface Media
- 2.11.4.6 Polygrid
- 2.11.4.7 Florcor
- 2.11.4.8 Single Stage Filter
- 2.11.4.9 Multiple Stage Filter
- 2.11.4.10 High Rate Single Stage Filter
- 2.11.4.11 High Rate Multiple Stage Filter
- 2.11.4.12 Redwood Media
- 2.11.4.13 Trickling Filter-Aerator Combination
- 2.11.4.14 Contact Aeration
- 2.11.4.15 Activated Bio-Filtration
- 2.11.4.16 Pack TOR
- 2.11.4.17 Duo-Distributor

2.11.5 Other Aerobic Systems

- 2.11.5.1 Biological Contactor Without Sludge Recycle
- 2.11.5.2 Biological Disc
- 2.11.5.3 Biological Cooling Tower
- 2.11.5.4 Bio Drum
- 2.11.5.5 Clarigester
- 2.11.5.6 Hy-Flo Fluidized Bed Treatment
- 2.11.5.7 Rotating Biological Surface Process

2.12 Oxidation Processes

2.12.1 Wet Thermal Processes (See also Section 3.5.3)

- 2.12.1.1 Astro Wet Oxidation Waste Treatment
- 2.12.1.2 PROST System
- 2.12.1.3 Heat Treatment

2. LIQUID TREATMENT (Cont.)

2.12.1 Wet Thermal Processes (See also Section 3.5.3)

  2.12.1.4 Sulfide Air Oxidation Process
  2.12.1.5 Zimpro Wet Oxidation Process

2.12.2 Surface Aerators

  2.12.2.1 Low Speed Surface Aerator
  2.12.2.2 Motor Speed Surface Aerator
  2.12.2.3 U-Tube Aeration System
  2.12.2.4 Pure Oxygen Surface Aeration
  2.12.2.5 Coke Tray Aerator
  2.12.2.6 Oxidation by Dilution
  2.12.2.7 Downflow Mechanical Aerator
  2.12.2.8 Upflow Mechanical Aerator
  2.12.2.9 Rotary Disk Aerator
  2.12.2.10 Sprays and Cooling Towers
  2.12.2.11 Waterfalls and Weirs
  2.12.2.12 Brush Aerators
  2.12.2.13 Ponds and Ditches
  2.12.2.14 Pressurized Aeration
  2.12.2.15 Turbine-Charged Liquid Oxygen System
  2.12.2.16 Foul Water/Spent Caustic Oxidation
  2.12.2.17 Bird Simplex SA Aerator
  2.12.2.18 Vortair Surface Entrainment Aerator
  2.12.2.19 Air Cone Aerators
  2.12.2.20 Cascade Aerators
  2.12.2.21 Floating Saucer Aerator

2.12.3 Subsurface Aeration

  2.12.3.1 Jet Aerator
  2.12.3.2 Multiple Jet Aerator
  2.12.3.3 Air Lift with Bow Tie Mixer
  2.12.3.4 Air Lift with Helical Mixer
  2.12.3.5 Air Lift Fermenter
  2.12.3.6 Self Priming Aerator
  2.12.3.7 Porous Diffuser
  2.12.3.8 Cord Wrapped Diffuser Tube
  2.12.3.9 Flexible-Bag Diffuser
  2.12.3.10 Perforated Pipe Diffuser
  2.12.3.11 Weighted Plate-Valve Diffuser
  2.12.3.12 Valve-and-seat Orifice Diffuser
  2.12.3.13 Variable Orifice Diffuser
  2.12.3.14 Multiple Orifice System
  2.12.3.15 Air-Water Impingement Diffuser
  2.12.3.16 Sparger Diffuser
  2.12.3.17 Air-Water Shear Diffuser
  2.12.3.18 Pure Oxygen Rotary Sparger
  2.12.3.19 Sparge Turbine Aerator
  2.12.3.20 Static Mixaerator
  2.12.3.21 Submersible Turbine Aerator

2. LIQUID TREATMENT (Cont.)

- 2.12.3 Subsurface Aeration (Cont.)
    - 2.12.3.22 Maximum Air Transfer Aerator
    - 2.12.3.23 Air-Aqua Controlled Aeration System
    - 2.12.3.24 Swing Arm Aerators
    - 2.12.3.25 Ring Jet Aerators
    - 2.12.3.26 DAT Aerator
- 2.12.4 Chemical Oxidation
    - 2.12.4.1 Chlorine
    - 2.12.4.2 Chlorination with Vaporizer
    - 2.12.4.3 Sodium Hypochlorite Solution
    - 2.12.4.4 Calcium Hypochlorite
    - 2.12.4.5 Kastone Process
    - 2.12.4.6 Permanganate Oxidation
    - 2.12.4.7 Ozonation Process
    - 2.12.4.8 Cyanide Oxidation Process
    - 2.12.4.9 Dupont Per Oxygen Compounds
    - 2.12.4.10 Hypochlorous Acid
    - 2.12.4.11 Chlorine Dioxide
    - 2.12.4.12 Hydrogen Peroxide
- 2.12.5 Catalytic Oxidation
    - 2.12.5.1 Vapor Phase Catalytic Oxidation
- 2.12.6 Incineration
    - 2.12.6.1 Super Heating Incinerator
    - 2.12.6.2 Dorr-Oliver Flo Solids Disposal System
    - 2.12.6.3 Cyclonic Incinerator
    - 2.12.6.4 Atomized Sludge Incineration Process
    - 2.12.6.5 Stationary Liquid Waste Burner
    - 2.12.6.6 Thermal Sub-X Combustion System
    - 2.12.6.7 Liqui-Datur
    - 2.12.6.8 Prenco Super E^3 System

2.13 Activated Carbon and Other Adsorbents

- 2.13.1 Powdered Absorbent Systems
    - 2.13.1.1 Three Step Once Through System
    - 2.13.1.2 Single Stage Contacting System
    - 2.13.1.3 Two Stage Countercurrent System
    - 2.13.1.4 Quik Tube Carbon Cartridges
- 2.13.2 Granular Absorbent Systems
    - 2.13.2.1 Downflow Fixed Bed
    - 2.13.2.2 Moving Bed
    - 2.13.2.3 Expanded Bed

2. LIQUID TREATMENT (Cont.)

- 2.13.2 Granular Absorbent Systems (Cont.)
    - 2.13.2.4 Upflow Fixed Bed
    - 2.13.2.5 Upflow Air Fluidized Bed
- 2.13.3 Activated Carbon Processes
    - 2.13.3.1 Hydrolysis Adsorption Process
- 2.13.4 Other Adsorption Systems
    - 2.13.4.1 Granular Condensate Resins
    - 2.13.4.2 Granular Addition Polymers
    - 2.13.4.3 Activated Alumina
    - 2.13.4.4 Hydroxyapatite
    - 2.13.4.5 Ambersorb Carbonaceous Absorbents
    - 2.13.4.6 Hay Filter

2.14 Ion Exchange Systems

- 2.14.1 Batch
    - 2.14.1.1 Pressure Tank Zeolite
    - 2.14.1.2 Two-Bed Weak Base Demineralizer
    - 2.14.1.3 Two-Bed Strong Base Demineralizer
    - 2.14.1.4 Three-Bed Demineralizer
    - 2.14.1.5 Four-Bed Primary with Weak Base
    - 2.14.1.6 Four-Bed Primary with Strong Base
    - 2.14.1.7 Dual Layered Two-Bed System
    - 2.14.1.8 Strong Base Anionic Mixed Bed
    - 2.14.1.9 Weak Base Anionic Mixed Bed
    - 2.14.1.10 Cation Modified Mixed Bed
    - 2.14.1.11 Three-Bed Cation-Anion Mixed Bed
    - 2.14.1.12 Weak Acid Cation Dealkalizer
    - 2.14.1.13 Strong Acid Cation Dealkalizer
    - 2.14.1.14 Blended Hydrogen-Sodium Dealkalizer
    - 2.14.1.15 Zeolite Ammonia Removal
    - 2.14.1.16 Organic Scavenger Trap
    - 2.14.1.17 Anion Desilicizer
    - 2.14.1.18 Maganese Zeolite-Potassium Permanganate
    - 2.14.1.19 Powdex^R Process
- 2.14.2 Continuous
    - 2.14.2.1 ASAHI Continuous Demineralizer
    - 2.14.2.2 Desol Process
    - 2.14.2.3 Chem-Seps Process
    - 2.14.2.4 One Train Higgins Softener
    - 2.14.2.5 Sul-bi-Sul Process
    - 2.14.2.6 Countercurrent Moving Bed System
    - 2.14.2.7 Graver C.I. Process

2. LIQUID TREATMENT (Cont.)

2.15 Cooling Towers and Ponds

2.15.1 Wet Towers

2.15.1.1 Crossflow-Natural Draft Spray
2.15.1.2 Crossflow-Natural Draft Packed
2.15.1.3 Counterflow-Induced Draft
2.15.1.4 Single Entry-Crossflow Induced Draft
2.15.1.5 Double Entry-Crossflow Induced Draft
2.15.1.6 Forced Draft
2.15.1.7 Hyperbolic Crossflow Natural Draft
2.15.1.8 Hyperbolic Counterflow Natural Draft
2.15.1.9 Induced Draft Spray
2.15.1.10 Fan-Assisted Natural Draft
2.15.1.11 Parallel Path Wet-Dry Tower

2.15.2 Dry Towers

2.15.2.1 Natural Draft Direct
2.15.2.2 Mechanical Draft Direct
2.15.2.3 Heller Type Natural Draft
2.15.2.4 Induced Draft Heller Type

2.15.3 Cooling Ponds

2.15.3.1 Cooling Pond
2.15.3.2 Spray Pond
2.15.3.3 Baffled Ponds
2.15.3.4 Induced Air Spray Cooling
2.15.3.5 Thermal - Rotor Spray System

2.16 Chemical Reaction and Separation

2.16.1 Processes

2.16.1.1 Aqua Claus Process
2.16.1.2 Chemfix Process
2.16.1.3 Woodall-Duckham Effluent Process
2.16.1.4 Sulfur Reduction
2.16.1.5 Andco Electrochemical Heavy Metal Removal Process
2.16.1.6 Cyanide Conversion to NH_3 and Sodium Formate
2.16.1.7 Mitsubishi Heavy Metal Recovery

2.16.2 Other Equipment

2.16.2.1 Lindman Precipitator

2.17 Water Intake Structures

2.17.1 Filtration Type (See also Section 2.5.1 & 2.5.6)

2.17.1.1 Wood Piling
2.17.1.2 Inverted Cone/Stone Riprap

2. LIQUID TREATMENT (Cont.)

2.17.1 Filtration Type (Cont.)

2.17.1.3 Simple Intake Screen
2.17.1.4 Porous Oike
2.17.1.5 Johnson Deepwater Screen
2.17.1.6 Johnson Shallow Water Screen
2.17.1.7 Perforated Pipe Laterals with Caissan
2.17.1.8 Ranney Surface Water Intake
2.17.1.9 Infiltration Barrier
2.17.1.10 Air Bubble Piping with Fixed Screen
2.17.1.11 Inclined Screen with Pliable Fish Brush
2.17.1.12 Lowered Offshore Intake
2.17.1.13 Rotating Vertical Screen
2.17.1.14 Double Screen with Fish Pump
2.17.1.15 Double-Entry Vertical Traveling Screen
2.17.1.16 Double-Exit Basket Shaped Panels
2.17.1.17 Double Screen with Fish Escape
2.17.1.18 Multifarious Water Intake Structure

2.17.2 Direct Flow Type

2.17.2.1 Dunne Crib Intake
2.17.2.2 Direct Intake with Breakwater
2.17.2.3 Shoreline Intake with Trash Rack
2.17.2.4 Intake Canal with Trash Rack
2.17.2.5 Air Bubble Ring
2.17.2.6 Electrical Barriers
2.17.2.7 Light Barriers
2.17.2.8 Sound Barriers
2.17.2.9 Hanging Chains
2.17.2.10 Water Current Modification

3. SOLIDS TREATMENT

3.1 Fixation

3.1.1 Physical Stabilization

3.1.1.1 Bituminization
3.1.1 2 Carbonate Bonding
3.1.1.3 Blending with Concrete
3.1.1.4 Blending with Asphalt
3.1.1.5 Blending with Synthetic Polymers
3.1.1.6 Lime Sludge Stabilization with Fly Ash
3.1.1.7 Koch Sludge Dehydration Process
3.1.1.8 Encapsulation in a Polyester Matrix

3.1.2 Calcination (See also Section 3.3)

3.1.2.1 Indirect-Heat Rotary Calciner
3.1.2.2 Cocurrent - Flow Calciner
3.1.2.3 Batch Retort

3.1.3 Chemical Fixation

3.1.3.1 Poz-O-Tec ^{R} Process
3.1.3.2 Calcilox
3.1.3.3 Chemfix Process
3.1.3.4 Neutralization of Spent Acid Catalysts

3.2 Recovery/Utilization

3.2.1 Extraction Processes

3.2.1.1 Sulfur Recovery from Spent Iron Oxide
3.2.1.2 Precious Metals Recovery from Spent Catalyst
3.2.1.3 Sulfur Recover from Coal Refuse

3.2.2 Regeneration Processes

3.2.2.1 Regeneration of Spent Nickle Catalysts
3.2.2.2 Chemical Reactivation of Spent Activated Carbon
3.2.2.3 Steam Reactivation of Spent Activated Carbon
3.2.2.4 Thermal Regeneration of Spent Activated Carbon
3.2.2.5 Wet Air Regeneration of Activated Carbon
3.2.2.6 Lime Reclamation
3.2.2.7 Vacuum Regeneration of Spent Activated Carbon

3.3 Processing/Combustion

3.3.1 Fixed Bed Incinerators

3.3.1.1 Single Chamber
3.3.1.2 Retort Type Multiple Chamber
3.3.1.3 In-line Type Multiple Chamber

3. SOLIDS TREATMENT (Cont.)

3.3.1 Fixed Bed Incinerators (Cont.)

- 3.3.1.4 Tray Furnace
- 3.3.1.5 Controlled Air Incinerator
- 3.3.1.6 Underground Burning
- 3.3.1.7 Air Curtain Distructor
- 3.3.1.8 Enertherm Cyclonic Incinerator
- 3.3.1.9 Kelly/Hoskinson Pyrolytic Incinerator System

3.3.2 Moving Bed Incinerators

- 3.3.2.1 Traveling Grate
- 3.3.2.2 Reciprocating Grate
- 3.3.2.3 Martin Reverse-Acting Reciprocating Grate
- 3.3.2.4 Rotary Hearth Furnace
- 3.3.2.5 Rotary Kiln
- 3.3.2.6 Rotating Drum Grate
- 3.3.2.7 Rocking Grate
- 3.3.2.8 Circular Cone Grate
- 3.3.2.9 Multiple Hearth Furnace
- 3.3.2.10 Vortex Incenerator (Suspension Firing)
- 3.3.2.11 C-E Raymond Flash Drying and Incineration
- 3.3.2.12 Volund Forward Pushing Step Grate
- 3.3.2.13 Basket Type Furnace
- 3.3.2.14 Semi Suspension Firing
- 3.3.2.15 Horizontal Cyclone Furnace
- 3.3.2.16 Shaft Kiln
- 3.3.2.17 Tip Grate
- 3.3.2.18 Pyro-Cone
- 3.3.2.19 Ecologizer
- 3.3.2.20 Thermal Reductor
- 3.3.2.21 Flash Drying/Incinerator

3.3.3 Fluidized Bed Incinerators

- 3.3.3.1 Novotny'y Process
- 3.3.3.2 Dorr-Oliver FS Disposal System
- 3.3.3.3 Copeland Process
- 3.3.3.4 American Oil Fluid Bed Incinerator
- 3.3.3.5 Black Clawson Process
- 3.3.3.6 Hercules Solid Waste Disposal System
- 3.3.3.7 CPU 400 Process

3.3.4 Slagging Incinerators

- 3.3.4.1 Sira System
- 3.3.4.2 Dravol/FLK Incinerator
- 3.3.4.3 American Thermogen System
- 3.3.4.4 Ferro-Tech System
- 3.3.4.5 Torrax System
- 3.3.4.6 Electric-Furnace System

3. SOLIDS TREATMENT (Cont.)

3.3.4 Slagging Incinerators (Cont.)

- 3.3.4.7 Oxygen-Enrichment System
- 3.3.4.8 Urban Research and Development Process

3.3.5 Pyrolysis Processes

- 3.3.5.1 USBM Pyrolysis Process
- 3.3.5.2 Monsanto Landgard System
- 3.3.5.3 Garrett Process
- 3.3.5.4 Union Carbide Pyrolysis Process
- 3.3.5.5 Fluidized Bed Pyrolysis
- 3.3.5.6 Lantz Process
- 3.3.5.7 Firestone Process
- 3.3.5.8 Goodyear Process
- 3.3.5.9 Devco Process
- 3.3.5.10 Austin Process
- 3.3.5.11 Destrugas Process
- 3.3.5.12 Pyrolysis - Combustion Process
- 3.3.5.13 Surface Sludge Disposal System
- 3.3.5.14 Waste Wood Pyrolysis

3.3.6 Heat Recovery Systems

- 3.3.6.1 Water Wall Incinerators
- 3.3.6.2 Packaged Fire Tube Boiler/Incinerator
- 3.3.6.3 Waste Addition to Conventional Boiler Feed

3.4 Chemical Reaction and Separation

3.5 Oxidation/Digestion

3.5.1 Composting

- 3.5.1.1 Naturizer System
- 3.5.1.2 Fairfield-Hardy Process
- 3.5.1.3 Riker Process
- 3.5.1.4 Batch Windrow Process
- 3.5.1.5 Dano Bio-Stabilizer Process
- 3.5.1.6 Cobey-Terex Process
- 3.5.1.7 Raspins Process
- 3.5.1.8 Varro Process
- 3.5.1.9 T. A. Crain Process
- 3.5.1.10 Earp Thomas Process
- 3.5.1.11 Metrowaste Conversion Process
- 3.5.1.12 Snell High Rate Process
- 3.5.1.13 Snell Forced Air Area Process
- 3.5.1.14 Frazer-Eweson
- 3.5.1.15 Jersey Process
- 3.5.1.16 Crude Composting in Landfills
- 3.5.1.17 Multi-Bactor Compost Tower
- 3.5.1.18 Caspari-Brikollare Process

3. SOLIDS TREATMENT (Cont.)

3.5.2 Anaerobic Digestion

- 3.5.2.1 Single Stage Conventional Digester
- 3.5.2.2 Two Stage Conventional Digester
- 3.5.2.3 Mechanically Mixed Conventional Digester
- 3.5.2.4 Gas Recirculated Conventional Digester
- 3.5.2.5 Anaerobic Lagoons
- 3.5.2.6 Partially Aerated Lagoons
- 3.5.2.7 Covered Anaerobic Lagoons
- 3.5.2.8 High Rate Digestion
- 3.5.2.9 Imhoff Tank
- 3.5.2.10 Anaerobic Contact Process
- 3.5.2.11 Anaerobic Filter
- 3.5.2.12 Septic Tank

3.5.3 Wet Oxidation

- 3.5.3.1 Earthworm Digestion
- 3.5.3.2 Aerobic Digestion

3.6 Physical Separation

3.6.1 Air Classification (See also Section 7.1.7)

- 3.6.1.1 SRI Zigzag Air Classifier
- 3.6.1.2 USBM Horizontal Air Classifier
- 3.6.1.3 Air Density Separator
- 3.6.1.4 Bauer Specific Gravity Separator
- 3.6.1.5 Mechanical Vacuum - Gravity Separator
- 3.6.1.6 Gayco Centrifugal Classifier
- 3.6.1.7 Raymond Whizzer Classifier
- 3.6.1.8 Strutevant Whirlwind Classifier
- 3.6.1.9 Hardinge Loop Classifier
- 3.6.1.10 Double-Cone Classifier
- 3.6.1.11 Hardinge Superfine Classifier
- 3.6.1.12 Mechanical Type Gravity Inertial Classifier
- 3.6.1.13 Vibro Lutiator
- 3.6.1.14 Dual Vortex Air Classifier
- 3.6.1.15 Gyratory Air Classifier
- 3.6.1.16 Williams Spinner Classifier
- 3.6.1.17 Roder Air Density Separator
- 3.6.1.18 Air Sifter
- 3.6.1.19 Centri-Sifter
- 3.6.1.20 Microplex Spiral Air Classifier

3.6.2 Hydraulic Classification (See also Section 7.1)

- 3.6.2.1 Black Clawson Hydraposal System
- 3.6.2.2 Wemco RC Separator
- 3.6.2.3 Surface Current Slime Tank
- 3.6.2.4 Callow Tank

3. SOLIDS TREATMENT (Cont.)

3.6.2 Hydraulic Classification (Cont.)

3.6.2.5 Shallow-Pocket Free-Settling Classifier
3.6.2.6 Deep-Pocket Free-Settling Classifier
3.6.2.7 Free-Settling Tank Classifier
3.6.2.8 Tank-Type Hindered-Settling Classifier
3.6.2.9 Fahrenwald Sizer
3.6.2.10 Bunker Hill Classifier
3.6.2.11 Pellett Classifier
3.6.2.12 Concenco Classifier
3.6.2.13 Delano Classifier
3.6.2.14 Centrifugal Classifier
3.6.2.15 Countercurrent Classifier
3.6.2.16 Jet Sizer
3.6.2.17 Super Sorter
3.6.2.18 D-O Suphon Sizer
3.6.2.19 Hydroscillator
3.6.2.20 Eagle Vari-Stroke Jig

3.6.3 Flotation (See also Section 2.3 and 7.1.6)

3.6.3.1 Murex Process
3.6.3.2 Wood Film - Flotation Machine
3.6.3.3 DeBavay Film - Flotation Process
3.6.3.4 Macquisten Film - Flotation Machine
3.6.3.5 Cascade Flotation Machine
3.6.3.6 Kand K Machine
3.6.3.7 Kraut Machine
3.6.3.8 Agglomeration Table

3.6.4 Electrostatic Separation

3.6.4.1 Plate Type Separator
3.6.4.2 Conductive Induction Rotary Separator
3.6.4.3 High Tension Rotary Separator

3.6.5 Magnetic Separation

3.6.5.1 Magnetic Pully
3.6.5.2 Concurrent Wet Drum Separator
3.6.5.3 Dry Drum Separator
3.6.5.4 Cross-Belt High Intensity Separator
3.6.5.5 Induced-Roll Separator
3.6.5.6 Suspended Type Magnet Separator
3.6.5.7 Counterrotation Wet Drum Separator
3.6.5.8 Grate Magnet
3.6.5.9 Magnetic Filter
3.6.5.10 Alternating-Polarity Drum Separator
3.6.5.11 Uni-Gap Drum Separator
3.6.5.12 High Speed Dry Magnetic Separator
3.6.5.13 High Gradient Magnetic Separator

3. SOLIDS TREATMENT (Cont.)

- 3.6.6 Screens (See also Section 2.4.8 to 2.4.13)

  - 3.6.6.1 Cantilever Grizzly
  - 3.6.6.2 Trommel
  - 3.6.6.3 Compound Trommel
  - 3.6.6.4 Mechanical Shaking
  - 3.6.6.5 Syntron Mechanical-Conveyor Shaking
  - 3.6.6.6 Mechanically Vibrating
  - 3.6.6.7 Electrically Vibrating
  - 3.6.6.8 Oscillating
  - 3.6.6.9 Reciprocating
  - 3.6.6.10 Gyratory
  - 3.6.6.11 Perforated Screen
  - 3.6.6.12 Step-Tread Screen
  - 3.6.6.13 Woven Wire Cloth Screen
  - 3.6.6.14 Profile Rod Screen
  - 3.6.6.15 Vibrating Cloth Screen
  - 3.6.6.16 Self Cleaning Grizzly
  - 3.6.6.17 Moving-Bar Grizzly
  - 3.6.6.18 Traveling Grizzly
  - 3.6.6.19 Roller Type Grizzly
  - 3.6.6.20 Live-Roll Grizzly
  - 3.6.6.21 Burch Ring Grizzly
  - 3.6.6.22 Shaking Grizzly
  - 3.6.6.23 Radar Disc Screen
  - 3.6.6.24 Rotascreen

- 3.6.7 Vibrating Classifiers (See also Section 7.1.5)

  - 3.6.7.1 Stoner Vibrating Table
  - 3.6.7.2 Dry Table

- 3.6.8 Evaporation

  - 3.6.8.1 Fluidized Bed Dryer
  - 3.6.8.2 Externally Heated Drum Dryer
  - 3.6.8.3 Spiral-Conveyor Dryer
  - 3.6.8.4 Steam Tube Rotary Dryer
  - 3.6.8.5 Vibratory Conveyor Dryer
  - 3.6.8.6 Agitated Pan Dryer
  - 3.6.8.7 Rotary Steam Tube Dryer
  - 3.6.8.8 Multi-Louvre Dryer
  - 3.6.8.9 Vacuum-Belt Dryer
  - 3.6.8.10 Vacuum Rotary Dryer
  - 3.6.8.11 Double Cone Vacuum Dryer

- 3.6.9 Mechanical Classification (See also Section 2.1.3)

  - 3.6.9.1 Dewatering Elevator
  - 3.6.9.2 Drag Classifier
  - 3.6.9.3 Rake Classifier

3. SOLIDS TREATMENT (Cont.)

3.6.9 Mechanical Classification (Cont.)

- 3.6.9.4 Shovel Wheel
- 3.6.9.5 Rotoscoop
- 3.6.9.6 Sand Wheel
- 3.6.9.7 Spiral Classifier
- 3.6.9.8 Hardinge Countercurrent Classifier

3.6.10 Miscellaneous Equipment

- 3.6.10.1 Ballistic Separator
- 3.6.10.2 Secator Inertial Separator
- 3.6.10.3 Inclined - Conveyor Separator
- 3.6.10.4 Sortex Optical Separation Unit

4. FINAL DISPOSAL

4.1 Pond Lining

- 4.1.1 Membrane Linings
  - 4.1.1.1 Butyl Rubber
  - 4.1.1.2 Ethylene Propylene Diene Monomer (EPDM)
  - 4.1.1.3 Neoprene
  - 4.1.1.4 Polyvinyl Chloride (PVC)
  - 4.1.1.5 Chlorosulforated Polyethylene (Hypalon)
  - 4.1.1.6 Chlorinated Polyethylene
  - 4.1.1.7 High Density Polyethylene
  - 4.1.1.8 Polyethylene
  - 4.1.1.9 Polypropylene
  - 4.1.1.10 Polyolefin (3110)
  - 4.1.1.11 Polyurethane
  - 4.1.1.12 Polyester (Hytrel)
  - 4.1.1.13 Fiberglass
  - 4.1.1.14 Asphaltic Flexible Sheeting
- 4.1.2 Liquid Sealants
  - 4.1.2.1 Epoxy Bituminous Coating
  - 4.1.2.2 Epoxy Tar Coating
  - 4.1.2.3 Rubber Latex
- 4.1.3 Bulk Materials
  - 4.1.3.1 Compacted Native Fine-Grain Soil
  - 4.1.3.2 Soil Cement
  - 4.1.3.3 Clay
  - 4.1.3.4 Concrete
  - 4.1.3.5 Hydralic Asphalt-Concrete
  - 4.1.3.6 Asphalt
  - 4.1.3.7 Impervious Pollution Barrier

4.2 Deep Well Injection

- 4.2.1 Surface Equipment
  - 4.2.1.1 Pretreatment Equipment
  - 4.2.1.2 Gravity Injection
  - 4.2.1.3 Centrifugal Pumps
  - 4.2.1.4 Multiplex Piston Pump
  - 4.2.1.5 Turbine Pump
- 4.2.2 Injection Techniques
  - 4.2.2.1 Cased-Hole Well Completion
  - 4.2.2.2 Open-Hole Well Completion
  - 4.2.2.3 Gravel Pack Completion
  - 4.2.2.4 Lined Injection Tube with Annular Fluid

4. FINAL DISPOSAL (Cont.)

4.2.2 Injection Techniques (Cont.)

- 4.2.2.5 Acidizing
- 4.2.2.6 Hydraulic Fracturing
- 4.2.2.7 Mechanical Treatment
- 4.2.2.8 Reinjection with Secondary Oil Recovery
- 4.2.2.9 Reinjection as a Grout or Cement Mixture
- 4.2.2.10 Selection of Disposal Strata
- 4.2.2.11 Ranney Recharge Collector

4.3 Burial and Landfill

4.3.1 Transportation

- 4.3.1.1 Air Tramway
- 4.3.1.2 Belt Conveyor
- 4.3.1.3 Trucks and Scrapers
- 4.3.1.4 Hydraulic Disposal
- 4.3.1.5 Pneumatic Conveyor

4.3.2 Landfill Methods

- 4.3.2.1 Deep Slurry Impoundment
- 4.3.2.2 Layered Flat Land Disposal
- 4.3.2.3 Layered Ravine Disposal
- 4.3.2.4 Lined Burial Pits
- 4.3.2.5 Refuse Stabilization with Limestone Waste
- 4.3.2.6 Shallow Slurry Impoundment
- 4.3.2.7 Strip Mine Disposal During Reclamation
- 4.3.2.8 Trench Method
- 4.3.2.9 Ramp Method
- 4.3.2.10 High Density Landfilling
- 4.3.2.11 Solidification/Landfill

4.4 Sealed Contained Storage

4.4.1 Encapsulation for Ocean Disposal

- 4.4.1.1 Corrosion Resistant Tanks
- 4.4.1.2 Concrete Encased Tanks

4.4.2 Encapsulation for Land Burial

- 4.4.2.1 Encapsulating Waste in Asphalt
- 4.4.2.2 Long Term High-Integrity Containers
- 4.4.2.3 Spray Calciner and Continuous Melter
- 4.4.2.4 Subsurface Trenches

4.4.3 Permanent Storage

- 4.4.3.1 Underground Mines
- 4.4.3.2 Tanks

4.5 Dilution (water)

4.5.1 Diffusers

- 4.5.1.1 Open-end Subsurface Pipe
- 4.5.1.2 Surface Discharge - Ditch
- 4.5.1.3 Surface Discharge - Pipe
- 4.5.1.4 Branched Pipe Diffuser
- 4.5.1.5 Slotted Pipe Diffuser
- 4.5.1.6 Nozzle End Pipe Diffuser
- 4.5.1.7 Perforated Pipe Diffuser
- 4.5.1.8 Vortex Generator

4.5.2 Ocean Disposal

- 4.5.2.1 Single Skin Barge
- 4.5.2.2 Double Skin Barge
- 4.5.2.3 Double Skin Barge with Independent Cargo Spaces
- 4.5.2.4 Caustic Disposal by Oil Tanker

4.6 Dispersion (air,land)

4.6.1 Tall Stacks

- 4.6.1.1 Masonry Lined Stacks
- 4.6.1.2 Plastic Lined Stacks
- 4.6.1.3 Monolithic Lined Stacks

4.6.2 Land Irrigation

- 4.6.2.1 Ridge and Furrows Irrigations
- 4.6.2.2 Spray Irrigation with Artificial Underground Drainage
- 4.6.2.3 Overland Spray Irrigation
- 4.6.2.4 Truck Irrigation

4.6.3 Spreading/Plowing In

- 4.6.3.1 Surface/Subsurface Distribution
- 4.6.3.2 Sand Farm Subsurface Injection
- 4.6.3.3 Surface Spreading

4.7 Waste Utilization

4.7.1 Reuse After Treatment/Conversion Processes

- 4.7.1.1 Activated Carbon from Coal Refuse
- 4.7.1.2 Steam Cured Bricks from Fly Ash

4. FINAL DISPOSAL (Cont.)

4.7.1 Reuse After Treatment/Conversion Processes (Cont.)

4.7.1.3 Stabilized Roadbase Material from Fly Ash
4.7.1.4 Granular Aggregate from Fly Ash
4.7.1.5 Spent Sulfuric Acid Regeneration
4.7.1.6 Ammonium Sulfate from Spent Sulfuric Acid

4.7.2 Direct Utilization

4.7.2.1 Water Treatment Sludge as Soil Conditioner
4.7.2.2 Acid Mine Drainage Sludge as Soil Conditioner
4.7.2.3 Poz-O-Pac-Process
4.7.2.4 Fly Ash for Soil Stabilization
4.7.2.5 Fly Ash as a Pozzolanic Additive in Cement
4.7.2.6 Spent Caustic for Industrial Uses
4.7.2.7 Spent Phosphoric Acid for Filler in Fertilizers
4.7.2.8 Disposal By Sale

4.7.3 Other Uses

4.7.3.1 Waste Heat for Space Heating
4.7.3.2 Waste Heat in Greenhouses
4.7.3.3 Waste Heat in Crop Farming
4.7.3.4 Waste Heat in Sewage Treatment
4.7.3.5 Waste Heat for Wastewater Evaporation
4.7.3.6 Waste Heat To De-ice Airport Runways

5. PROCESS MODIFICATIONS

5.1 Feedstock, Raw Material Changes

5.1.1 Alternate Water Sources

5.1.1.1 Surface Water
5.1.1.2 Ground Water
5.1.1.3 Brackish Water
5.1.1.4 Sea Water
5.1.1.5 Collected Runoff

5.1.2 Water Treatment Chemicals

5.1.2.1 Non-Chromate Corrosion Inhibitors
5.1.2.2 Non-Phenol Algacides

5.1.3 Gas Treatment Chemicals

5.1.3.1 High Grade Limestone for FGD Scrubbers
5.1.3.2 Water as Absorbent

5.2 Stream Recycle

5.2.1 Direct Recycle

5.2.1.1 Reuse of Refinery Washes
5.2.1.2 Sour Water Stripper Bottoms
5.2.1.3 Boiler Blowdown to Cooling Towers
5.2.1.4 Recycle of Coal Gasification Tars
5.2.1.5 Use of Foul Water in Desalting
5.2.1.6 Spent Caustic to Neutralize Flue Gas
5.2.1.7 Spent Caustic/Waste Acid Neutralization

5.2.2 Reuse After Treatment

5.2.2.1 Refinery Wastewater
5.2.2.2 Delayed Coke Drilling Water
5.2.2.3 Tank Water Draws
5.2.2.4 Acid Mine Drainage Water
5.2.2.5 Regenerated Spent Catalyst
5.2.2.6 Agglomerated Fly Ash Recycle to Boiler
5.2.2.7 Caustic Regeneration
5.2.2.8 Isomerization Neutralizer Waste as Flocculant

5.2.3 Waste Heat Recovery

5.2.3.1 Process Heating
5.2.3.2 Boiler Feedwater Heating
5.2.3.3 Absorption Refrigeration

5. PROCESS MODIFICATIONS (Cont.)

5.3 Process Improvements

5.3.1 Equalization of Waste Flows

- 5.3.1.1 Equalization Tanks
- 5.3.1.2 Ponds
- 5.3.1.3 Gas Holders

5.3.2 Improved Equipment Cleaning Methods

- 5.3.2.1 Biodegradable Detergents
- 5.3.2.2 Closed Tank Cleaning Systems
- 5.3.2.3 Improved Chemical Tank Cleaning

5.3.3 Educational Programs for Pollution Control

- 5.3.3.1 In-Plant Training for Pollution Control
- 5.3.3.2 Information Transfer from Pilot Plant Studies
- 5.3.3.3 Spill Prevention and Control Programs

5.3.4 Improved Process Control Instrumentation

- 5.3.4.1 Continuous Monitoring
- 5.3.4.2 Centralized Control
- 5.3.4.3 Computerized Control

5.3.5 Process Modifications

- 5.3.5.1 Use of Cooling Tower as Biological Oxidation Unit

5.3.6 Improved Operating Procedures

- 5.3.6.1 Startup Procedures
- 5.3.6.2 Shut Down Procedures
- 5.3.6.3 Optimization of Operating Conditions

6. COMBUSTION MODIFICATIONS

6.1 Combustion Furnace/Burner/Process Modifications

6.1.1 Low Excess Air Firing

- 6.1.1.1 Gas Fired Utility Boilers
- 6.1.1.2 Oil Fired Utility Boilers
- 6.1.1.3 Coal Fired Utility Boilers
- 6.1.1.4 Gas Fired Industrial/Commercial Boilers
- 6.1.1.5 Oil Fired Industrial/Commercial Boilers
- 6.1.1.6 Coal Fired Industrial
- 6.1.1.7 Gas Fired Residential Warm Air Furnaces
- 6.1.1.8 Distillate Oil Fired Residential Warm Air Furnaces

6.1.2 Flue Gas Recirculation

- 6.1.2.1 Gas Fired Utility Boilers
- 6.1.2.2 Oil Fired Utility Boilers
- 6.1.2.3 Gas Fired Industrial/Commercial Boilers
- 6.1.2.4 Oil Fired Industrial/Commercial Boilers
- 6.1.2.5 Gas Fired Internal Combustion Engines
- 6.1.2.6 Diesel Oil Fired Internal Combustion Engines
- 6.1.2.7 Dual Fuel Fired Internal Combustion Engines
- 6.1.2.8 Gas Fired Gas Turbine Engines
- 6.1.2.9 Oil Fired Gas Turbine Engines

6.1.3 Off-Stoichiometric/Staged Combustion

- 6.1.3.1 Gas Fired Utility Boilers
- 6.1.3.2 Oil Fired Utility Boilers
- 6.1.3.3 Coal Fired Utility Boilers
- 6.1.3.4 Gas Fired Industrial/Commercial Boilers
- 6.1.3.5 Oil Fired Industrial/Commercial Boilers
- 6.1.3.6 Coal Fired Industrial/Commercial Boilers

6.1.4 Burner/Furnace Design Modifications

- 6.1.4.1 Gas Fired Utility Boilers
- 6.1.4.2 Oil Fired Utility Boilers
- 6.1.4.3 Coal Fired Utility Boilers
- 6.1.4.4 Gas Fired Industrial/Commercial Boilers
- 6.1.4.5 Oil Fired Industrial/Commercial Boilers
- 6.1.4.6 Coal Fired Industrial/Commercial Boilers
- 6.1.4.7 Distillate Oil Fired Residential Warm Air Furnaces
- 6.1.4.8 Gas Fired Internal Combustion Engines
- 6.1.4.9 Diesel Oil Fired Internal Combustion Engines
- 6.1.4.10 Gas Fired Gas Turbine Engines
- 6.1.4.11 Oil Fired Gas Turbine Engines

6. COMBUSTION MODIFICATIONS

6.1.5 Load Reduction

6.1.5.1 Gas Fired Utility Boilers
6.1.5.2 Oil Fired Utility Boilers
6.1.5.3 Coal Fired Utility Boilers
6.1.5.4 Gas Fired Industrial/Commercial Boilers
6.1.5.5 Oil Fired Industrial/Commercial Boilers
6.1.5.6 Coal Fired Industria/Commercial Boilers
6.1.5.7 Gas Fired Residential Warm Air Furnaces
6.1.5.8 Distillate Oil Fired Residential Warm Air
6.1.5.9 Gas Fired Internal Combustion Engines
6.1.5.10 Diesel Oil Fired Internal Combustion Engines
6.1.5.11 Dual Fuel Fired Internal Combustion Engines
6.1.5.12 Gas Fired Gas Turbine Engines
6.1.5.13 Oil Fired Gas Turbine Engines

6.1.6 Reduced Air Preheat

6.1.6.1 Gas Fired Utility Boilers
6.1.6.2 Oil Fired Utility Boilers
6.1.6.3 Coal Fired Utility Boilers
6.1.6.4 Gas Fired Industrial/Commercial Boilers
6.1.6.5 Oil Fired Industrial/Commercial Boilers
6.1.6.6 Coal Fired Industrial/Commercial Boilers
6.1.6.7 Gas Fired Internal Combustion Engines
6.1.6.8 Diesel Oil Fired Internal Combustion Engines
6.1.6.9 Dual Fuel Fired Internal Combustion Engines

6.1.7 Water/Steam Injection

6.1.7.1 Oil Fired Utility Boilers
6.1.7.2 Coal Fired Utility Boilers
6.1.7.3 Gas Fired Internal Combustion Engines
6.1.7.4 Diesel Oil Fired Internal Combustion Engines
6.1.7.5 Dual Fuel Fired Internal Combustion Engines
6.1.7.6 Gas Fired Gas Turbine Engines
6.1.7.7 Oil Fired Gas Turbine Engines

6.1.8 Combination of Above Modifications

6.1.8.1 Gas Fired Utility Boilers
6.1.8.2 Oil Fired Utility Boilers
6.1.8.3 Coal Fired Utility Boilers
6.1.8.4 Gas Fired Industrial/Commercial Boilers
6.1.8.5 Oil Fired Industrial/Commercial Boilers
6.1.8.6 Coal Fired Industrial/Commercial Boilers
6.1.8.7 Gas Fired Residential Warm Air Furnaces
6.1.8.8 Distillate Oil Fired Residential Warm Air Furnaces
6.1.8.9 Gas Fired Internal Combustion Engines
6.1.8.10 Diesel Oil Fired Internal Combustion Engines
6.1.8.11 Dual Fuel Fired Internal Combustion Engines
6.1.8.12 Gas Fired Gas Turbine Engines
6.1.8.13 Oil Fired Gas Turbine Engines

6. COMBUSTION MODIFICATIONS

6.2 Equipment Maintenance

- 6.2.1 Burner Tuning
- 6.2.2 Soot Removal
- 6.2.3 Water Treatment (when applicable)
- 6.2.4 Proper Operation
  - 6.2.4.1 Automatic
  - 6.2.4.2 Manual
- 6.2.5 Other

6.3 Alternate Fuels/Processes

- 6.3.1 Natural Fuels
  - 6.3.1.1 Low Sulfur Coal
  - 6.3.1.2 Low Sulfur Oil
  - 6.3.1.3 Others
- 6.3.2 Mixed Fuels
  - 6.3.2.1 Coal/Oil Slurries
  - 6.3.2.2 Oil/Water Emulsions
  - 6.3.2.3 Coal/Oil/Water Mixtures
  - 6.3.2.4 Mixture with Municipal Waste
  - 6.3.2.5 Mixture with Industrial Waste
- 6.3.3 Synthetic Fuels
  - 6.3.3.1 Low BTU Gas from Coal
  - 6.3.3.2 Medium and High BTU Gas from Coal
  - 6.3.3.3 Substitute Natural Gas
  - 6.3.3.4 Methanol
  - 6.3.3.5 Coal-derived Liquids
  - 6.3.3.6 Shale-derived Liquids
  - 6.3.3.7 Processed Coals/Solid Fuels
- 6.3.4 Alternate Processes
  - 6.3.4.1 Fluidized Bed Combustion
  - 6.3.4.2 Catalytic Combustion
  - 6.3.4.3 Others (MHD, etc.)

6.4 Fuel Additives/Furnace Reactants

- 6.4.1 Smoke and Particulate Suppressants
  - 6.4.1.1 Transition Metal Compounds
  - 6.4.1.2 Alkaline Earth Metal Compounds

6. COMBUSTION MODIFICATIONS

6.4.1 Smoke and Particulate Suppressants (Cont.)

- 6.4.1.3 Others

6.4.2 Sulfur Oxide Reducers

- 6.4.2.1 Lime
- 6.4.2.2 Limestone
- 6.4.2.3 Soda Ash
- 6.4.2.4 Others

6.4.3 Corrosion/Slagging/Deposits Control

- 6.4.3.1 Alkaline Earth Metal Compounds
- 6.4.3.2 Others

6.4.4 Nitrogen Oxides Reducers

- 6.4.4.1 Ammonia

6.4.5 Fly Ash Conditioners

- 6.4.5.1 Sulfur Oxides

7. FUEL CLEANING (Cont.)

7.1 Physical Separation

7.1.1 Dense Media Separation

7.1.1.1 American Cyanamid HMS Process
7.1.1.2 Barvoys Vessel
7.1.1.3 Belknap Calcium Chloride Washer
7.1.1.4 Chance Sand Cone Process
7.1.1.5 DMS Dense Medium Precision Coal Washer
7.1.1.6 DSM Trough-Type Vessel
7.1.1.7 Eagle Hi-Grade Media Coal Washer
7.1.1.8 External Airlift Conical Separator
7.1.1.9 H & P Heavy Media Wash Box
7.1.1.10 Link-Belt Tank Type Heavy Medium Separator
7.1.1.11 McNally Lo-Flo Dense Media Vessel
7.1.1.12 McNally Tromp Dense Media Bath
7.1.1.13 McNally Tromp Three Product Dense Media Vessel
7.1.1.14 Modified Spiral Classifier
7.1.1.15 NELDCO Submerged Feed Processor
7.1.1.16 OCC Vessel
7.1.1.17 Teska Vessel
7.1.1.18 WEMCO Cone Separator
7.1.1.19 WEMCO Drum Separator
7.1.1.20 WEMCO-FP Washer
7.1.1.21 Heavy Media Static Bath

7.1.2 Centrifugal Separators

7.1.2.1 Krebs Coal Cleaning Cyclone
7.1.2.2 McNally Heavy Media Cycloid
7.1.2.3 McNally Visman Tricone
7.1.2.4 Wilmot Dyna Whirlpool Vessel
7.1.2.5 Heavy Media Coal Cleaning Cyclone
7.1.2.6 Var-A-Wall Hydrocyclone

7.1.3 Jigs

7.1.3.1 Batac Jig
7.1.3.2 Elmore Plunger Jig
7.1.3.3 Faust Plunger Jig
7.1.3.4 Jeffrey Air Operated Jig
7.1.3.5 Jeffrey Diaphragm Jig
7.1.3.6 Lehigh Punger Jig
7.1.3.7 Link-Belt Air Pulsated Wash Box
7.1.3.8 McNally Fine Coal Washer
7.1.3.9 McNally-Pittsburg Mogul Washer
7.1.3.10 McNally-Pittsburg Norton Standard Washer
7.1.3.11 ORC Fine Coal Washer
7.1.3.12 Reading Jig
7.1.3.13 Roberts and Shaefer Fine Coal Jig
7.1.3.14 Tacub Jig

7. FUEL CLEANING (Cont.)

7.1.3 Jigs (Cont.)

- 7.1.3.15 Vissac Jig
- 7.1.3.16 WEMCO-Remer Jig
- 7.1.3.17 Wilmot Simplex Pan Jig

7.1.4 Launders

- 7.1.4.1 Batelle Washer
- 7.1.4.2 Cannon Concentrator
- 7.1.4.3 Deposite Particle Launder
- 7.1.4.4 Free Discharge Rheolaveur
- 7.1.4.5 Humphrey Spiral Concentrator
- 7.1.4.6 Hydraulic Classifier
- 7.1.4.7 Hydrotator Process
- 7.1.4.8 Lamex Launder
- 7.1.4.9 Menzie Cone Hydroseparator
- 7.1.4.10 Multidune Process
- 7.1.4.11 Reichert Concentrator
- 7.1.4.12 Sealed Discharge Rheolaveur

7.1.5 Wet Concentrating Tables

- 7.1.5.1 Massco
- 7.1.5.2 Garfield
- 7.1.5.3 Butchart
- 7.1.5.4 Diester
- 7.1.5.5 Campbell
- 7.1.5.6 Buss
- 7.1.5.7 Plat-O
- 7.1.5.8 Overstrom Universal

7.1.6 Froth Flotation (See also Section 2.3)

- 7.1.6.1 D-R Flotation Machine
- 7.1.6.2 Denver Cell
- 7.1.6.3 Galigher Agitair Flotation Machine
- 7.1.6.4 WEMCO 1+1 Flotation Cells
- 7.1.6.5 H & P Cyclo-Cell

7.1.7 Other Commercial Methods

- 7.1.7.1 Dry Centrifugal Separation
- 7.1.7.2 Roberts and Shaefer Airflow Cleaner
- 7.1.7.3 Selective Flocculation
- 7.1.7.4 Rotary Breaker
- 7.1.7.5 Ziegler Picker
- 7.1.7.6 Ayers Picker
- 7.1.7.7 Shaking Picker
- 7.1.7.8 Spiral Picker

7. FUEL CLEANING (Cont.)

7.2 Chemical Refining

7.3 Carbonization/Pyrolysis

7.3.1 Vertical Retorts

7.3.1.1 Brennstoff-Technak
7.3.1.2 Carmaux Oven
7.3.1.3 Cellon Jones Oven
7.3.1.4 Koppers Continuous Vertical Report
7.3.1.5 Krupp-Lurgi Process
7.3.1.6 Otto Retort
7.3.1.7 Parker Retort
7.3.1.8 Phurnacite Process
7.3.1.9 Rexco Process
7.3.1.10 Weber Process

7.3.2 Horizontal Retorts

7.3.3 Entrained or Fluidized Carbonization

7.3.3.1 Parry Entrained Carbonization Process

7.4 Treatment of Liquid Fuels

7.4.1 Physical Chemical Methods

7.4.1.1 Demex
7.4.1.2 Molecular Sieve Drying and Sweeting
7.4.1.3 Solvent Deasphalting
7.4.1.4 Stripping of Crude Fuels

7.4.2 Hydrotreating

7.4.2.1 Autofining (BP Trading)
7.4.2.2 Bender Sweetening (Petrolite)
7.4.2.3 DPG Hydrotreating (C-E Lummus)
7.4.2.4 Distillate HDS (IFP)
7.4.2.5 Fuel HDS (IFP)
7.4.2.6 GO-fining and RESID Fining (Exxon)
7.4.2.7 Gulfining (Gulf)
7.4.2.8 H-Oil (Hydrocarbon Research)
7.4.2.9 HDS (M. W. Kellogg)
7.4.2.10 HPN (Engelhard Industries)
7.4.2.11 Hydrocracking (BP Trading)
7.4.2.12 Hydrocracking (IFP)
7.4.2.13 Hydrofining (BP Trading)
7.4.2.14 Hydrofining (Exxon)
7.4.2.15 Isocracking (Chevron)
7.4.2.16 LC-Fining (C-E Lummus)

7. FUEL CLEANING (Cont.)

7.4.2 Hydrotreating (Cont.)

- 7.4.2.17 Locap (Petrolite)
- 7.4.2.18 Mercapfining (Howe-Baker)
- 7.4.2.19 PGO Hydrotreating (C-E Lummus)
- 7.4.2.20 Propane Deasphalting and Fractionation (Pullman Kellogg)
- 7.4.2.21 Pyrolysis Distillate Hydrogenation (IFP)
- 7.4.2.22 RCD Unibon (UOP)
- 7.4.2.23 RDS and VRDS Hydrotreating (Chevron)
- 7.4.2.24 Redis HDS (Gulf)
- 7.4.2.25 Resid Hydroprocessing (Standard)
- 7.4.2.26 Residual Oil HDS (Shell)
- 7.4.2.27 Residue Desulfurization (BP Trading)
- 7.4.2.28 Trickle Flow HDS (Shell)
- 7.4.2.29 Ultrafining (Standard)
- 7.4.2.30 Ultrasweetening (Standard)
- 7.4.2.31 Unicracking/HDS (Union Oil)
- 7.4.2.32 Unionfining (Union Oil)
- 7.4.2.33 VGO and DAO Hydrotreating (Chevron)
- 7.4.2.34 Vapor Phase HDS (Shell)

7.4.3 Chemical Treatment

- 7.4.3.1 Atlantic Unisol
- 7.4.3.2 Catalytic Demetalization
- 7.4.3.3 Cooper Sweetening - Dry
- 7.4.3.4 Cooper Sweetening - Slurry
- 7.4.3.5 Distillate Treating (Petrolite)
- 7.4.3.6 Doctor Treatment - Mercaptan Oxidation
- 7.4.3.7 Dualayer Distillate Process (Socony Mobil Oil)
- 7.4.3.8 Electrical Distillate Treating (Howe-Baker)
- 7.4.3.9 Furfural Extraction of Gas Oils (Texaco)
- 7.4.3.10 Gray Desulfurization Process
- 7.4.3.11 Hypochlorite Treatment - Mercaptan Oxidation
- 7.4.3.12 Inhibitor Sweetening
- 7.4.3.13 Lead Sulfide Treatment - Mercaptan Oxidation
- 7.4.3.14 Merifining (Merichem)
- 7.4.3.15 Merox (UOP)
- 7.4.3.16 Perco Catalytic Process
- 7.4.3.17 Polysulfide Elemental Sulfur Removal
- 7.4.3.18 Pure Oil Mercapsol Process
- 7.4.3.19 Regenerative Caustic Process
- 7.4.3.20 Selective Oxidation and Extraction
- 7.4.3.21 SO_2 Extraction (Edeleanu Gesellschaft)
- 7.4.3.22 Solutizer (Shell)
- 7.4.3.23 Sulfining (Howe-Baker)

7.5 Fuel Gas Treatment

7.5.1 Absorption (See also Section 1.4)

- 7.5.1.1 Absorption by Caustic Soda
- 7.5.1.2 Acid Gas Adsorption in Organic Solvents

7. FUEL CLEANING (Cont.)

7.5.1 Absorption (Cont.)

7.5.1.3 Adip (Shell)
7.5.1.4 Alkacid Process (Davy Powergas)
7.5.1.5 Amisol Process
7.5.1.6 Carl Still Process
7.5.1.7 Catacarb Process
7.5.1.8 DEA Process
7.5.1.9 DGA Process
7.5.1.10 DIPA Process
7.5.1.11 Direct Ammonia Removal Process
7.5.1.12 Estasolvan Process
7.5.1.13 F-S Process
7.5.1.14 Fluor Econamine
7.5.1.15 Fluor Solvent Process
7.5.1.16 Girbotol Process
7.5.1.17 Glycol-Amine Process
7.5.1.18 H_2S Adsorption in Water
7.5.1.19 Heat Exchanger - Absorber Amine Process
7.5.1.20 High Pressure Adsorption of NH_3 in Water
7.5.1.21 Hot Potassium Carbonate/Benfield Process
7.5.1.22 Indirect Ammonia Removal Process
7.5.1.23 Klempt and Rober Pyridine Process
7.5.1.24 Lenze and Rettenmaier Refrigeration Process
7.5.1.25 Lime Slurry Process
7.5.1.26 MEA Process
7.5.1.27 MDEA Process (DOW)
7.5.1.28 Permanganate and Dichromate Adsorption
7.5.1.29 Purisol Process
7.5.1.30 Rectisol Process
7.5.1.31 Rectisol Process for Selective H_2S Removal
7.5.1.32 SNPA-DEA (Parsons)
7.5.1.33 Seaboard Gas Purification Process
7.5.1.34 Selective H_2S Removal/Collin Process
7.5.1.35 Selective H_2S Removal/No NH_3 Solution Recycle
7.5.1.36 Selective H_2S Removal/Partial Solution Recycle
7.5.1.37 Selexol Process
7.5.1.38 Semidirect Ammonia Removal Process
7.5.1.39 Sodium Bichromate/Zinc Sulfate Absorption
7.5.1.40 Split-Stream Aqueous Amine Process
7.5.1.41 Sulfiban Process
7.5.1.42 Sulfinol Process
7.5.1.43 Tripotassium Phosphate Process
7.5.1.44 USS Phosam Process
7.5.1.45 Vacuum Carbonate Process

7.5.2 Dry Oxidation (See also Section 1.7.2)

7.5.2.1 Applyby-Frodingham Process
7.5.2.2 Conventional-Box Fe_2O_3 Purifier

7. FUEL CLEANING (Cont.)

7.5.2 Dry Oxidation (Cont.)

- 7.5.2.3 Fe_2O_3 Deep-Box Purifier
- 7.5.2.4 Gastechnik Purification Process
- 7.5.2.5 High Pressure Fe_2O_3 Purifiers
- 7.5.2.6 Katasulf Process
- 7.5.2.7 North Thames Gas Board Process
- 7.5.2.8 Soda-Iron Process
- 7.5.2.9 Spichal Activated Carbon Process
- 7.5.2.10 Split-Stream Katasulf Process
- 7.5.2.11 Thyssen-Lenze Tower Purifiers

7.5.3 Liquid Phase Oxidation (See also Section 1.7.2)

- 7.5.3.1 Auto Purification Process
- 7.5.3.2 Fischer Process
- 7.5.3.3 Giammarco Vetrocoke Process
- 7.5.3.4 Gluud Combination Process
- 7.5.3.5 Koppers C.A.S. Process
- 7.5.3.6 Lacey-Keller Process
- 7.5.3.7 Manchester Process
- 7.5.3.8 Modified Thylox Process
- 7.5.3.9 Perox Process
- 7.5.3.10 Stretford Process
- 7.5.3.11 Takahax Process
- 7.5.3.12 Thylox Process
- 7.5.3.13 Townsend Process

7.5.4 Adsorption

- 7.5.4.1 CBA Process
- 7.5.4.2 Haines Process
- 7.5.4.3 Molecular Sieve/Liquid Absorbent Process
- 7.5.4.4 Zinc Oxide Adsorption

7.5.5 Catalytic Conversion (See also Section 1.7.2)

- 7.5.5.1 British Gas Council Process
- 7.5.5.2 Carpenter-Evans Process
- 7.5.5.3 Holmes-Maxted Process
- 7.5.5.4 Modified Holmes-Maxted Process
- 7.5.5.5 Organic Sulfur Removal-Chromia-Alumina Catalyst
- 7.5.5.6 Organic Sulfur Removal-Co Mo Catalyst
- 7.5.5.7 Organic Sulfur Removal-Huff Catalyst
- 7.5.5.8 Organic Sulfur Removal-Iron Oxide Catalyst
- 7.5.5.9 Organic Sulfur Removal-Platinum Catalyst
- 7.5.5.10 Peoples Gas Company Process

8. FUGITIVE EMISSIONS CONTROL

8.1 Surface Coatings/Covers

8.1.1 Surface Coatings

8.1.1.1 Alkyd Paints
8.1.1.2 Latex Paints
8.1.1.3 Epoxy-Coal Tar
8.1.1.4 Epoxy, Furan, Phenoloic, Polyester Resins
8.1.1.5 Vinyl and Urethane Coatings
8.1.1.6 Neoprene, Chlorinated Rubber
8.1.1.7 Silicones
8.1.1.8 Silicate Cement
8.1.1.9 Asphalt Base Mastic
8.1.1.10 Plasticized Sulfur
8.1.1.11 Organic and Inorganic Zinc

8.1.2 Soil Covers

8.1.2.1 Aggregate
8.1.2.2 Asphalt
8.1.2.3 Gabions, Rip-Rap
8.1.2.4 Fibrous Matting
8.1.2.5 Plastic Sheeting
8.1.2.6 Filter Fabrics
8.1.2.7 Gobimat

8.1.3 Evaporation Barriers

8.1.3.1 Plastic Balls
8.1.3.2 Plastic Foam
8.1.3.3 Pan-Type Internal Covers
8.1.3.4 Aluminum Sandwich Floating Cover
8.1.3.5 Polyester-Foam Sandwich Cover
8.1.3.6 Foam Slabs
8.1.3.7 Liquid Evaporation Inhibitors

8.2 Vegetation

8.2.1 Barrier Plantings

8.2.1.1 Windbreaks
8.2.1.2 Noise Barriers
8.2.1.3 Dust Barriers

8.2.2 Erosion Control

8.2.2.1 Ground Covers
8.2.2.2 Slope Stabilizers
8.2.2.3 Contour Planting

8. FUGITIVE EMISSIONS CONTROL (Cont.)

8.2.3 Mined Land Reclamation

- 8.2.3.1 Grasses
- 8.2.3.2 Legumes
- 8.2.3.3 Shrubs
- 8.2.3.4 Trees

8.3 Dust Control Sprays

8.3.1 Spray Nozzles

- 8.3.1.1 Fan
- 8.3.1.2 Whirl
- 8.3.1.3 Impingement
- 8.3.1.4 Spiral
- 8.3.1.5 Air Atomizing

8.3.2 Spray Systems

- 8.3.2.1 Mobile Applicators
- 8.3.2.2 Solids Transfer Systems

8.3.3 Chemical Agents

- 8.3.3.1 Wetting Agents
- 8.3.3.2 Petroleum Resins
- 8.3.3.3 Lignon Sulfonate
- 8.3.3.4 Foaming Agents

8.4 Dust and/or Vapor Enclosures

8.4.1 Shrouds, Hoods and Covers

- 8.4.1.1 Vented Hoods
- 8.4.1.2 Trellex Dust-Proofing System
- 8.4.1.3 Air Curtains
- 8.4.1.4 Covers for API Separators
- 8.4.1.5 Covered Drains

8.4.2 Buildings

- 8.4.2.1 Air-Supported Structures
- 8.4.2.2 Negative Pressure Buildings
- 8.4.2.3 Ventilation Exhaust Scrubbers

8.5 Leak Prevention

8.5.1 Pond Liners and Sealants (See Sec. 4.1)

8. FUGITIVE EMISSIONS CONTROL (Cont.)

8.5.2 Tank Liners

- 8.5.2.1 Plastic Bag Liners
- 8.5.2.2 Cemented Vinyl
- 8.5.2.3 Liquid-Applied Coatings (See Sec. 8.1.1)
- 8.5.2.4 Lead
- 8.5.2.5 Rubber
- 8.5.2.6 Stonliner

8.5.3 Cathodic Protection

- 8.5.3.1 Galvanic Anodes
- 8.5.3.2 Impressed Current System

8.5.4 Dry-Break Couplings

- 8.5.4.1 API-1004

8.5.5 Shaft Seals

- 8.5.5.1 Mechanical Seals
- 8.5.5.2 Seal Impurity Eliminator
- 8.5.5.3 Secondary Seals, Pressurized
- 8.5.5.4 Secondary Seals, Vented

8.5.6 Gaskets and Other Seals

- 8.5.6.1 Elastomeric
- 8.5.6.2 Metal
- 8.5.6.3 Asbestos
- 8.5.6.4 Metal-Asbestos
- 8.5.6.4 Valve Packing

8.5.7 Piping Practice for Leak Prevention

- 8.5.7.1 Pipeline Welding Techniques
- 8.5.7.2 Protective Diaphragms for Relief Valves
- 8.5.7.3 Thermal Expansion Allowance

8.6 Leak Detection and Repair

8.6.1 Spill Detectors (Water Surface)

- 8.6.1.1 Spillalarm
- 8.6.1.2 Infrared Oil Film Monitor

8.6.2 Pipeline Slow Leak Detection

- 8.6.2.1 B&W Photography
- 8.6.2.2 Color Photography
- 8.6.2.3 Infrared Photography
- 8.6.2.4 Microwave Radiometry

8. FUGITIVE EMISSIONS CONTROL (Cont.)

- 8.6.3 Gas Leak Detectors
  - 8.6.3.1 Soap Solution
  - 8.6.3.2 Smoke Generators
  - 8.6.3.3 Thermal Conductivity
  - 8.6.3.4 Baghouse Leak Detector
  - 8.6.3.5 Flammable Gas Detector
  - 8.6.3.6 LNG Leak Detector
- 8.6.4 Leak Repairs
  - 8.6.4.1 Pipe Sleeves
  - 8.6.4.2 Flange Repair-Rings
  - 8.6.4.3 Oversleeves

8.7 Vent Vapor Controls

- 8.7.1 Variable Volume Storage Tanks
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  - 8.7.1.2 Pontoon-Type Floating Roof
  - 8.7.1.3 Sandwich-Type Floating Roof
  - 8.7.1.4 Flexible Diaphragm Tank
- 8.7.2 Seals for Floating Roof Tanks
  - 8.7.2.1 Shoe Seals
  - 8.7.2.2 Tube Seals
  - 8.7.2.3 Secondary Wiper Seals
  - 8.7.2.4 Secondary Tube Seals
- 8.7.3 Variable Vapor Space Systems
  - 8.7.3.1 Dry-Seal Lifter Roof
  - 8.7.3.2 Wet-Seal Lifter Roof
  - 8.7.3.3 Flexible Diaphragm, Integral Unit
  - 8.7.3.4 Flexible Diaphragm, Separate Unit
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  - 8.7.4.1 Shade
  - 8.7.4.2 Reflective Paint
  - 8.7.4.3 Insulation
  - 8.7.4.4 Water Cooling
- 8.7.5 Pressure-Vacuum Vent Valves
  - 8.7.5.1 Solid Pallet Valve
  - 8.7.5.2 Diaphragm Valve
  - 8.7.5.3 Pilot Operated Valves
  - 8.7.5.4 Cylindrical Liquid Seal
  - 8.7.5.5 Bell Type Liquid Seal
  - 8.7.5.6 Standpipe Liquid Seal

8. FUGITIVE EMISSIONS CONTROL (Cont.)

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- 8.7.6.2 Transit Tank Baffles
- 8.7.6.3 Submerged Fill
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8.7.7 Vapor Recovery

- 8.7.7.1 Vapor Balance Loading Systems
- 8.7.7.2 Vacuum Assisted Vapor Balance
- 8.7.7.3 Compression
- 8.7.7.4 Condensation (See also Section 1.5)
- 8.7.7.5 Absorption and Adsorption (See also Sec. 1.4, 1.6)
- 8.7.7.6 Gas Blanketing

8.7.8 Incineration (See Sec. 1.7)

8.7.9 Sampling Techniques

- 8.7.9.1 Pump-Around Sampling Loops
- 8.7.9.2 Hooded Sampling Points
- 8.7.9.3 Sample Bombs for Flushing
- 8.7.9.4 Combination Drain and Sample Valve

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- 8.8.1.2 Segregated Ballast
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8.8.2 Shipboard Oil-Water Separators

- 8.8.2.1 Filter Coalescer
- 8.8.2.2 Parallel Plate Coalescer

8.9 Noise Control

8.9.1 Barrier Surfaces

- 8.9.1.1 Mass-Loaded Vinyl Sheet
- 8.9.1.2 Lead Sheet
- 8.9.1.3 Damped Metals

8.9.2 Absorbing Materials

- 8.9.2.1 Asbestos Ceiling Tile
- 8.9.2.2 Urethane Foam
- 8.9.2.3 Fiberglass Blanket

8. FUGITIVE EMISSIONS CONTROL (Cont.)

- 8.9.2 Absorbing Materials (Cont.)
    - 8.9.2.4 Foam-Plastic Sandwich
    - 8.9.2.5 Felt
- 8.9.3 Enclosures
    - 8.9.3.1 Absorbing Masonry Blocks
    - 8.9.3.2 Metal Sandwich Panels
    - 8.9.3.3 Polyethylene-Fiberglass Wall Modules
    - 8.9.3.4 Polyurethane Sandwich Panels
- 8.9.4 Damping Coatings
    - 8.9.4.1 Mastic
    - 8.9.4.2 Adhesive Tap
- 8.9.5 Silencers/Attenuators
    - 8.9.5.1 Intake Absorbers
    - 8.9.5.2 Intake Snubbers
    - 8.9.5.3 Absorptive Ducts
    - 8.9.5.4 Exhaust Absorbers
    - 8.9.5.5 Exhaust Snubbers
    - 8.9.5.6 In-Line Valve Silencers
- 8.9.6 Sound Reduction Doors
    - 8.9.6.1 Solid
    - 8.9.6.2 Flexible Strip

8.10 Odor Control

- 8.10.1 Emissions Control (See Section 1,2,8,9)
- 8.10.2 Oxidation of Malodorous Spills
    - 8.10.2.1 Sodium Hypochlorite
    - 8.10.2.2 Potassium Permanganate
    - 8.10.2.3 Hydrogen Peroxide
- 8.10.3 Odor Masking
    - 8.10.3.1 Easton
    - 8.10.3.2 Plastocon
    - 8.10.3.3 Air-Tite

9. ACCIDENTAL RELEASE TECHNOLOGY

9.1 Spill Prevention in Storage Systems

- 9.1.1 Containment of Storage Spills
  - 9.1.1.1 Dikes, Curbs & Pits
  - 9.1.1.2 Catchment Tanks & Basins
  - 9.1.1.3 Separate Drainage for Diked Areas
  - 9.1.1.4 Stormwater Bypass Systems
  - 9.1.1.5 Non-Drained Dike Areas
  - 9.1.1.6 Imbibitive Polymer Valve
  - 9.1.1.7 Oil Stop Valve
- 9.1.2 Pressure & Vacuum Protection Devices
  - 9.1.2.1 Rupture Discs
  - 9.1.2.2 Spring Loaded Relief Valves
  - 9.1.2.3 Pilot Operated Safety Valves
  - 9.1.2.4 Vacuum Breakers
- 9.1.3 Level Alarms
  - 9.1.3.1 Hydrostatic
  - 9.1.3.2 Ultrasonic
  - 9.1.3.3 Thermistor
  - 9.1.3.4 Resistance
  - 9.1.3.5 Capacitance
  - 9.1.3.6 Separate Overflow & Alarm
  - 9.1.3.7 Spill Detectors (See Section 8.6.2)
  - 9.1.3.8 Float Type
- 9.1.4 Building Design for Containment
  - 9.1.4.1 Chemical Sewer System
  - 9.1.4.2 Vent Exhaust Scrubbers
  - 9.1.4.3 Ventilation Zoning
- 9.1.5 Security Measures and Procedures
  - 9.1.5.1 Locked or Sealed Drain Valves
  - 9.1.5.2 TV Surveillance

9.2 Spill Prevention in Transportation

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  - 9.2.1.1 Tank-in-Barge
- 9.2.2 Vessel Mooring and Transfer Systems
  - 9.2.2.1 T-Jetty
  - 9.2.2.2 Sea Island
  - 9.2.2.3 Single Point Mooring
  - 9.2.2.4 Double-Wall Transfer Hose

9. ACCIDENTAL RELEASE TECHNOLOGY (Cont.)

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    - 9.2.3.1 Coupling-Valve Interlocks
    - 9.2.3.2 Coupling-Departure Interlocks
    - 9.2.3.3 Quick Drainage Systems
    - 9.2.3.4 Loading Facility Drains
- 9.2.4 Catastrophic Leak Detection
    - 9.2.4.1 Closed Circuit TV
    - 9.2.4.2 Comparative Flow

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- 9.3.1 Blowout Preventers
    - 9.3.1.1 Ram
    - 9.3.1.2 Shear
    - 9.3.1.3 Annular
    - 9.3.1.4 Rotating
    - 9.3.1.5 Inside Drill Pipe
- 9.3.2 Containment Barriers for Offshore Platforms
    - 9.3.2.1 Permanent Booms
    - 9.3.2.2 Rising-Sinking Booms
- 9.3.3 Collection Devices for Submarine Leaks
    - 9.3.3.1 Firestone Fabri-Dome

9.4 Flares

- 9.4.1 Tower Flares
    - 9.4.1.1 Steam Injection
    - 9.4.1.2 Forced Air
    - 9.4.1.3 Entrained Air
- 9.4.2 Ground Flares
    - 9.4.2.1 Open
    - 9.4.2.2 Enclosed
- 9.4.3 Burn Pits
    - 9.4.3.1 Consumat

9. ACCIDENAL RELEASE TECHNOLOGY (Cont.)

9.5 Oil Spill Barriers

- 9.5.1 Floating Booms for Oil Spills
  - 9.5.1.1 Curtain Booms
  - 9.5.1.2 Fence Booms
  - 9.5.1.3 Collapsible Booms
  - 9.5.1.4 High Seas Booms
  - 9.5.1.5 Absorbent Booms
  - 9.5.1.6 High Current Booms
- 9.5.2 Barriers for Land or Small Streams
  - 9.5.2.1 Earth Dike
  - 9.5.2.2 Sorbent Fence
  - 9.5.2.3 Instant Foam Barrier
- 9.5.3 Chemical Barriers (Booming Agents)
  - 9.5.3.1 Shell Oil Herder
  - 9.5.3.2 Emery
  - 9.5.3.3 W. G. Smith
  - 9.5.3.4 Chevron
- 9.5.4 Air Barriers
  - 9.5.4.1 Harmstorff
  - 9.5.4.2 Hind Engineering
  - 9.5.4.3 Environmental Services

9.6 Oil Recovery Devices

- 9.6.1 Weir Devices
  - 9.6.1.1 Acme
  - 9.6.1.2 Mapco
  - 9.6.1.3 OELA
  - 9.6.1.4 Skim
  - 9.6.1.5 SLURP
  - 9.6.1.6 Bennett
  - 9.6.1.7 Rheinswerft
  - 9.6.1.8 Craftmaster
  - 9.6.1.9 PSI
- 9.6.2 Floating Suction Devices
  - 9.6.2.1 Kepner Seavac
  - 9.6.2.2 Oil Recovery Systems
  - 9.6.2.3 Slickbar
  - 9.6.2.4 Acme
  - 9.6.2.5 IME
  - 9.6.2.6 Vac-U-Max

9. ACCIDENTAL RELEASE TECHNOLOGY (Cont.)

9.6.2 Floating Suction Devices (Cont.)

  9.6.2.7 Megator
  9.6.2.8 Hyde
  9.6.2.9 Envirex
  9.6.2.10 Craftmaster

9.6.3 Oleophilic Surface Devices

  9.6.3.1 Rex Chainbelt
  9.6.3.2 Bennett Pollution Controls
  9.6.3.3 JBF Scientific
  9.6.3.4 Centri-Spray
  9.6.3.5 British Petroleum
  9.6.3.6 Lockheed
  9.6.3.7 Surface Separator Systems
  9.6.3.8 Welles Products
  9.6.3.9 Oil Skimmers
  9.6.3.10 Oil Mop
  9.6.3.11 Sandvik
  9.6.3.12 Tenco
  9.6.3.13 Met-Pro
  9.6.3.14 Marco
  9.6.3.15 Envirex
  9.6.3.16 Action Engineering

9.6.4 Vortexes and Misc. Mechanical Devices

  9.6.4.1 Vortex Oil Drinker
  9.6.4.2 Scientific Associates
  9.6.4.3 Cyclonet
  9.6.4.4 Intex
  9.6.4.5 Craftmaster

9.6.5 Combination Barrier-Skimmers

  9.6.5.1 CORE Laboratories
  9.6.5.2 MIT Design
  9.6.5.3 Ultrasystems
  9.6.5.4 Oil Mop
  9.6.5.5 Samson
  9.6.5.6 Offshore Devices

9.6.6 Mobile Skimmers

  9.6.6.1 JBF Scientific
  9.6.6.2 Gulf of Georgia Towing Co.
  9.6.6.3 Cyclonet
  9.6.6.4 Lockheed
  9.6.6.5 RBH Cybernetics
  9.6.6.6 Slickbar
  9.6.6.7 Craftmaster

9. ACCIDENTAL RELEASE TECHNOLOGY (Cont.)

9.6.6 Mobile Skimmers (Cont.)

- 9.6.6.8 Marco
- 9.6.6.9 Sandvik
- 9.6.6.10 Bennett
- 9.6.6.11 Seaward

9.6.7 Absorbents

- 9.6.7.1 Straw
- 9.6.7.2 Wood Fibers
- 9.6.7.3 Corn Cob
- 9.6.7.4 Peat
- 9.6.7.5 Perlite
- 9.6.7.6 Vermiculite
- 9.6.7.7 Volcanic Rock
- 9.6.7.8 Polyolefins
- 9.6.7.9 Polyurethanes
- 9.6.7.10 Other Synthetic Foams
- 9.6.7.11 Unclassified
- 9.6.7.12 Ferromagnetic Sorbent

9.6.8 Mobile Storage & Transfer Units

- 9.6.8.1 Towable Storage Bags
- 9.6.8.2 Land-Based Units
- 9.6.8.3 Towed Planning Sled

9.7 Chemical Treatment of Oil Spills

9.7.1 Dispersants

- 9.7.1.1 Soaps
- 9.7.1.2 Phosphate Detergents
- 9.7.1.3 Alkyl-aryl-sulfonates
- 9.7.1.4 Alkanolamides
- 9.7.1.5 Ethylene Oxide Condensates
- 9.7.1.6 Aromatic Solvents
- 9.7.1.7 Aliphatic Solvents
- 9.7.1.8 Polyglycols
- 9.7.1.9 Other

9.7.2 Sinking Agents

- 9.7.2.1 Clay Based
- 9.7.2.2 Silica Based
- 9.7.2.3 Aluminum and Magnesium Silicates
- 9.7.2.4 Asbestos
- 9.7.2.5 Cement, Gypsum
- 9.7.2.6 Calcium Carbonate
- 9.7.2.7 Miscellaneous

9. ACCIDENTAL RELEASE TECHNOLOGY (Cont.)

9.7.3 Gelling Agents

  9.7.3.1 Burns & Russell, Gel-Sorb 301
  9.7.3.2 Narvon Mining & Chemical, Zeta Floc
  9.7.3.3 Strickman Industries, Strickite Oil Collector
  9.7.3.4 Union Carbide, Calidria Asbestos

9.7.4 Burning Agents

  9.7.4.1 Cabot, Cab-O-Sil
  9.7.4.2 Grefco, Ekoperl
  9.7.4.3 Guardian Chemical, Pyraxon
  9.7.4.4 Pittsburgh Corning, Sea Beads
  9.7.4.5 Scheidemandel A. G., Kontax
  9.7.4.6 Vermiculite

9.7.5 Biological Treatment

  9.7.5.1 Bioteknika International, Biodeg and Petrodeg
  9.7.5.2 Gerald C. Bowers, DBC-Plus
  9.7.5.3 International Enzymes, Bacto-Zyme
  9.7.5.4 Hyde Park

9.8 Subsurface and Hazardous Spills

9.8.1 Recovery Methods for Subsurface Spills

  9.8.1.1 Recovery Trench
  9.8.1.2 Recovery Well
  9.8.1.3 Recovery Crock
  9.8.1.4 Barrier Curtain

9.8.2 Recovery Methods for Hazardous Materials

  9.8.2.1 Vacuum Trucks
  9.8.2.2 Mine Safety Appliance
  9.8.2.3 Floating Ion Exchange Resins
  9.8.2.4 Imbibitive Polymers

SELECTED SPECIFIC DEVICE DATA SHEETS

CLASSIFICATION
Gas Treatment

GENERIC DEVICE OR PROCESS
Liquid Scrubbers/Contactors (Absorption Processes)

SPECIFIC DEVICE OR PROCESS
Lime Slurry Process

NUMBER
1.4.1.1

POLLUTANTS CONTROLLED		AIR GASES		AIR PARTICULATES		WATER DISSOLVED		WATER SUSPENDED		LAND LEACHABLE		LAND FUGITIVE
☐	ORGANIC	☐		☐		☐		☐		☐		☐
☒	INORGANIC	☒	SO_2	☒	fly ash	☐		☐		☐		☐
☐	THERMAL											
☐	NOISE											

PROCESS DESCRIPTION

The lime slurry process is a nonregenerative, throwaway flue gas desulfurization (FGD) process. This process shown in Figure 1, and the limestone slurry process (1.4.1.2) are the most commonly applied commercial FGD processes in the United States. In most applications there are three sections to the process, an electrostatic precipitator (ESP) and two stages of lime scrubbing. Particulate is removed in the ESP and in the first stage venturi scrubber. SO_2 is removed primarily in the second stage scrubber, but a considerable amount (up to 20%) is removed in the first stage scrubber. A large variety of scrubber designs have been successfully used in both the first and second stages. Each of the manufacturers listed below can recommend a suitable combination[A]. With some systems the electrostatic precipitator can be eliminated by high efficiency particulate scrubbing in the first stage.

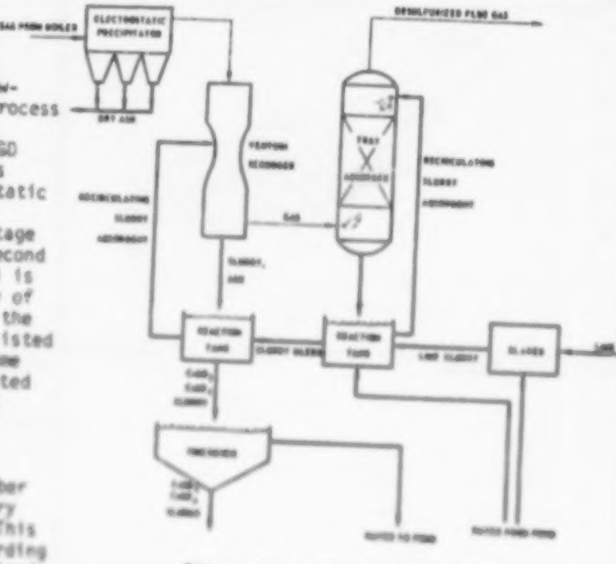

Figure 1. LIME SLURRY PROCESS

Lime (CaO) is slaked (reacted with water) to form calcium hydroxide ($Ca(OH)_2$), and is used in the scrubber recirculation system. SO_2 dissolves in the lime slurry (pH of 6.0 - 8.0) and forms sulfurous acid (H_2SO_3). This acid dissociates and reacts with the lime slurry according to reaction (1). The sulfurous acid can also be oxidized by any dissolved oxygen (reaction 2) and react with the lime slurry according to reaction (3) forming a calcium sulfuate precipitate, gypsum[B].

$$Ca(OH)_2 + H_2SO_3 \longrightarrow CaSO_3 \cdot 1/2H_2O + 1\text{-}1/2H_2O \qquad (1)$$

$$H_2SO_3 + 1/2\ O_2 \longrightarrow H_2SO_4 \qquad (2)$$

$$Ca(OH_2) + H_2SO_4 \longrightarrow CaSO_4 \cdot 2H_2O \qquad (3)$$

Cleaned gas from the scrubber is reheated typically to 175°F (80°C) and disposed of by tall stacks. The reheat step can be eliminated but this may create a visible water plume from the stack and an undesirable "acid rain" in cold weather. Ambient SO_2 concentrations may also increase.

Calcium sulfite/calcium sulfate slurry from both scrubbers is thickened and the resulting sludge can be disposed of in a pond (section 4.1), or fixed and disposed of in a landfill (sections 3.1 and 4.3 respectively). Sludge can also be oxidized in an air blown reactor to form an environmentally acceptable disposal sludge or to form by-product gypsum for use in the production of wallboard. Mitsubishi adds sulfuric acid to the oxidizer to ensure the proper pH for reaction and complete conversion to gypsum. They also add gypsum "seed" crystals to the scrubber solution to prevent scaling. Dravo and Pullman Kellogg have developed processes which use magnesium compounds as a additive to reduce scaling in the scrubber, increase absorption capacity, and to produce a more manageable by-product sludge.

APPLICATION RANGE

OPERATING REGIMES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	kPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	Btu/hr

The lime slurry process was developed to remove SO_2 from boiler flue gases and other combustion sources. With certain scrubbing systems, particulate control can also be accomplished in conjunction with SO_2 removal. Lime slurry scrubbing, without sludge oxidation is only applicable to plants which have an environmentally acceptable sludge disposal system. This process can be designed to meet a wide range of flow rates from 1000 SCFM for small industrial users to over 2.5 million SCFM for large utilities. SO_2 loadings as high as 4000 ppm have been reported.

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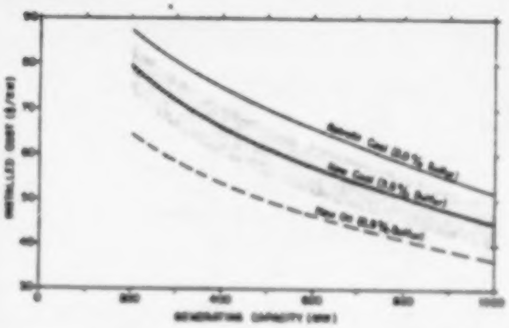
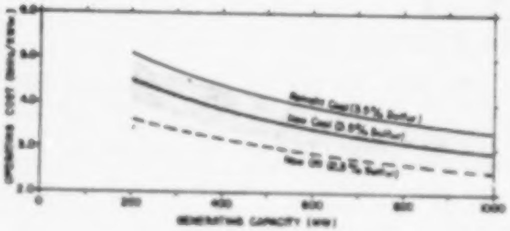
CAPITAL COSTS

Capital costs for the lime slurry process are shown below[1]. Costs were estimated by EPA/TVA for a startup in mid-1978. The costs shown are installed costs and are based on a 90% SO_2 removal efficiency. All costs are dependent upon the sulfur content of the fuel; the cost variance for FGD systems on new coal fired boilers is shown by the shaded area. The upper and lower limits correspond to 5.0 and 2.0% sulfur respectively.



OPERATING COSTS

Operating costs for lime scrubbing are shown below[1]. Costs were estimated by EPA/TVA using 1978 cost information. The costs shown are total operating costs[C] and are based upon a 90% SO_2 removal efficiency. All costs are dependent upon the sulfur content of the fuel; the cost variance for FGD systems on new coal fired boilers is shown by the shaded area. The upper and lower limits correspond to 5.0 and 2.0% sulfur respectively.



OPERATING EFFICIENCIES

SO_2 removal efficiencies are dependent upon several variables:

- reactivity of the scrubbing liquid,
- degree of gas - liquid contact,
- liquid to gas ratio,
- gas residence time, and
- the number of scrubber stages.

Almost any efficiency can be realized by adjusting the above factors. In most installations currently operating today, the efficiency has ranged between 80 and 90%.

A major contributor to low overall efficiency is scrubber maintenance, where the scrubber must be bypassed to facilitate repair or cleanout. This can be overcome by installing extra modules and transferring the load.

ENVIRONMENTAL PROBLEMS

The lime slurry process may create environmental problems in the following areas:

1. Large quantities of waste must be disposed of in an environmentally acceptable manner.
2. Stack emissions may create an "acid rain" under certain weather conditions if reheat is not provided.
3. Low scrubber availability may increase the overall SO_2 emissions, if alternate control facilities or methods are not provided.

NOTES

A. The scrubbers which can be used in this process are described in detail in sections 1.4.2 to 1.4.10
B. SO_2 can also be oxidized in the gas phase to SO_3 which would react similarly to form gypsum.
C. The cost data include amortized capital investments, overhead, utilities, raw materials, labor and maintenance; but do not include by-products credits or fixation costs.

MANUFACTURERS/SUPPLIERS

American Air Filter Co., Inc.
Babcock & Wilcox Co.
Chiyoda Chemical Engineering and Construction Co., Ltd.
Combustion Engineering, Inc.
Combustion Equipment Associates, Inc.
Dravo Corp.
Environeering Inc., Division of Riley Stoker
Envirotech Corp., Chemico Air Pollution Control Division
Koch Engineering Co.
Mitsubishi Heavy Industries, Inc.
Nippon Kokan KK
Pullman Kellogg, Division of Pullman, Inc.
Research Cottrell, Industrial Division
Southern California Edison
UOP Inc., Air Correction Division
Zurn Industries, Inc.

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1) "Proceedings: Symposium on Flue Gas Desulfurization, New Orleans, March 1976, Volume I", U.S. Environmental Protection Agency, EPA 600/2-76-136a, (May 1976).
2) Federal Power Commission, "The Status of Flue Gas Desulfurization Applications in the United States: A Technological Assessment", A staff report of the Bureau of Power, July 1977.
3) Electric Power Research Institute, "Evaluation of Regenerable Flue Gas Desulfurization Process", EPRI FP-272, Volumes 1 and 2 (January 1976).

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Gas Treatment	Liquid Scrubbers/Contactors (Absorption Processes)

SPECIFIC DEVICE OR PROCESS	NUMBER
Limestone Slurry Process	1.4.1.2

POLLUTANTS CONTROLLED		AIR				WATER				LAND			
		GASES		PARTICULATES		DISSOLVED		SUSPENDED		LEACHABLE		FUGITIVE	
☐	ORGANIC	☐		☐		☐		☐		☐		☐	
x	INORGANIC	x	SO_2	x	fly ash	☐		☐		☐		☐	
☐	THERMAL												
☐	NOISE												

PROCESS DESCRIPTION

The limestone slurry process is a non-regenerative, throwaway flue gas desulfurization (FGD) process. This process, shown in Figure 1, and the lime slurry process (1.4.1.1) are the most commonly applied commercial FGD processes in the United States. In most applications there are three sections to the process, an electrostatic precipitator (ESP), and two stages of limestone scrubbing. Particulate matter is removed in the ESP and in the first stage venturi scrubber. SO_2 is removed primarily in the second stage, but a considerable amount (up to 20%) is removed in the first scrubbing stage. A large variety of scrubber designs have been successfilly used in both the first and second scrubbing stages. Each of the manufacturers listed below can recommend a suitable combination[A]. With some systems, the ESP can be eliminated by high efficiency particulate scrubbing in the first stage.

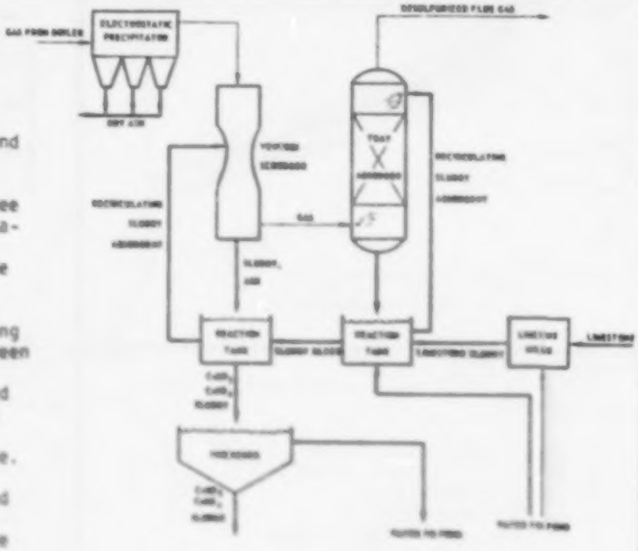


Figure 1. LIMESTONE SLURRY PROCSS

Limestone, containing as much as 95% $CaCO_3$ and varying amounts of $MgCO_3$, is crushed in a wet ball mill and pumped as a slurry to the absorber recycle system. Pilot studies have been conducted to investigate the use of benzoic acid to aid in the dissolution of the limestone[1]. SO_2 dissolves in the limestone slurry (pH = 5.8-6.4) and forms sulfurous acid (H_2SO_3). The sulfurous acid reacts with the dissolved $CaCO_3$ according to reaction (1). $CaCO_3$ wil also react with the oxidized sulfur compounds (H_2SO_4) to form gypsum as shown in reaction (2).

$$CaCO_3 + H_2SO_3 \longrightarrow CaSO_3 \cdot 1/2H_2O + CO_2 + 1/2H_2O \qquad (1)$$

$$CaCO_3 + H_2SO_4 \longrightarrow CaSO_4 \cdot 2H_2O + CO_2 \qquad (2)$$

Cleaned gas from the scrubber is reheated typically to 175°F (80°C) and disposed of by tall stack. The reheat step can be eliminated but this may create a visible water plume from the stack and an undesirable "acid rain" in cold weather. Ambient SO_2 concentrations may also increase.

Calcium sulfite/calcium sulfate slurry from both scrubbers is thickened and the resulting sludge can be disposed of in a pond (section 4.1), or is fixed and disposed of in a landfill (sections 3.1 and 4.3 respectively). Typically the sludge in the limestone process has a better settling rate than the lime slurry process.

Unlike the magnesium content in lime, the higher the magnesium content in limestone ($MgCO_3$), the lower the reactivity for sulfur removal. However, some developers, suggest the use of a catalyst to increase sorptivity, reduce scaling, and to produce an easily oxidized sludge[B]. Sludge, when oxidized in an air blown reactor can be used as an environmentally acceptable disposal sludge or to form by-product gypsum.

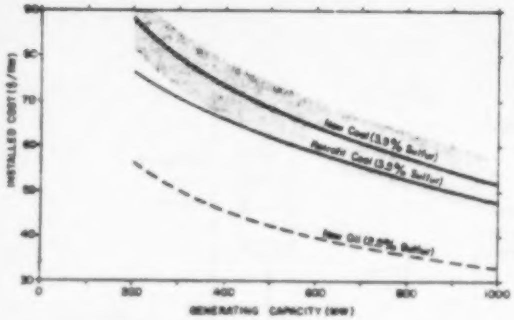
APPLICATION RANGE

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	kPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	Btu/hr

The limestone slurry process was developed to remove SO_2 from boiler flue gases and other combustion sources. With certain scrubbing systems, particulate control can also be accomplished in conjunction with SO_2 removal. Limestone slurry scrubbing, without sludge oxidation is only applicable to plants which have an environmentally acceptable sludge disposal system. This process can be designed to meet a wide range of flue rates from 1000 SCFM for small industrial users to over 3.5 million SCFM for large utilities. SO_2 loadings as high as 4000 ppm have been reported.

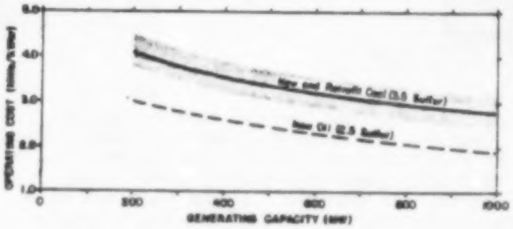
CAPITAL COSTS

Capital costs for the limestone slurry process are shown below[1]. Costs were estimated by EPA/TVA for a startup in mid-1978. The costs shown are installed costs and are based on a 90% SO_2 removal efficiency. All costs are dependent upon the sulfur content of the fuel; the cost variance for FGD systems on new coal fired boilers is shown by the shaded area. The upper and lower limits correspond to 5.0 and 2.0% sulfur respectively.



OPERATING COSTS

Operating costs for limestone scrubbing are shown below[1]. Costs were estimated by EPA/TVA using 1978 cost information. The costs shown are total operating costs[C] and are based upon a 90% SO_2 removal efficiency. All costs are dependent upon the sulfur content of the fuel; the cost variance for FGD systems on new coal fired boilers is shown by the shaded area. The upper and lower limits correspond to 5.0 and 2.0% sulfur respectively.



OPERATING EFFICIENCIES

SO_2 removal efficiencies are dependent upon several variables:

- reactivity of the scrubbing liquid,
- degree of gas-liquid contact,
- liquid to gas ratio,
- gas residence time, and
- the number of scrubber stages.

Almost any efficiency can be realized by adjusting the above factors. In most installations currently operating today, the efficiency has ranged between 80 and 98%.

A major contributor to low overall efficiency is scrubber maintenance, where the scrubber must be by-passed to facilitate repair or cleanout. This can be overcome by installing extra modules and transferring the load.

ENVIRONMENTAL PROBLEMS

The limestone slurry process may create environmental problems in the following areas:

1. Large quantities of waste must be disposed of in an environmentally acceptable manner.
2. Stack emissions may create an "acid rain" under certain weather conditions if reheat is not provided.
3. Low scrubber availability may increase the overall SO_2 emissions, if alternate control facilities or methods are not provided.

NOTES

A. The scrubbers which can be used in this process are described in detail in sections 1.4.2 to 1.4.10

B. Mitsubishi adds gypsum "seed" crystals to the absorption slurry to provide seed sites for the $CaSO_4$ crystallation. This helps prevent scaling. They also use sulfuric acid in the oxidizer to ensure the proper pH for reaction, and to guarantee complete conversion.

C. The cost data include amortized capital investments, overhead, utilities, raw materials, labor and maintenance; but do not include by-product credits, or fixation costs.

MANUFACTURER/SUPPLIER

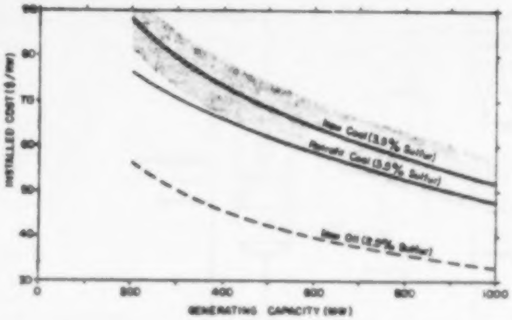
Babcock & Wilcox Co.
Chiyoda Chemical Engineering and Construction Co., Ltd.
Combustion Engineering, Inc.
Environeering Inc., Division of Riley Stoker
Envirotech Corp., Chemico Air Pollution Control Division
Mitsubishi Heavy Industries, Ltd.
Peabody Air Resources, Inc.
Pullman Kellogg, Division of Pullman, Inc.
Research Cottrell, Industrial Division
Tennessee Valley Authority
UOP Inc., Air Correction Division
Zurn Industries, Inc.

REFERENCES

1. "Proceedings: Symposium on Flue Gas Desulfurization, New Orleans, March 1976, Volume 1", U.S. Environmental Protection Agency, EPA 600/2-76-136a, (May 1976).
2. Federal Power Commission, "The Status of Flue Gas Desulfurization Applications in the United States: A Technological Assessment", A staff report of the Bureau of Power, July 1977.
3. Electric Power Research Institute, "Evaluation of Regenerable Flue Gas Desulfurization Process", EPRI FP-272, Volumes 1 and 2 (January 1977).

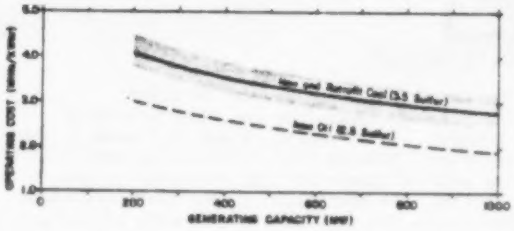
CAPITAL COSTS

Capital costs for the limestone slurry process are shown below[1]. Costs were estimated by EPA/TVA for a startup in mid-1978. The costs shown are installed costs and are based on a 90% SO_2 removal efficiency. All costs are dependent upon the sulfur content of the fuel; the cost variance for FGD systems on new coal fired boilers is shown by the shaded area. The upper and lower limits correspond to 5.0 and 2.0% sulfur respectively.



OPERATING COSTS

Operating costs for limestone scrubbing are shown below[1]. Costs were estimated by EPA/TVA using 1978 cost information. The costs shown are total operating costs[C] and are based upon a 90% SO_2 removal efficiency. All costs are dependent upon the sulfur content of the fuel; the cost variance for FGD systems on new coal fired boilers is shown by the shaded area. The upper and lower limits correspond to 5.0 and 2.0% sulfur respectively.



OPERATING EFFICIENCIES

SO_2 removal efficiencies are dependent upon several variables:

- reactivity of the scrubbing liquid,
- degree of gas-liquid contact,
- liquid to gas ratio,
- gas residence time, and
- the number of scrubber stages.

Almost any efficiency can be realized by adjusting the above factors. In most installations currently operating today, the efficiency has ranged between 80 and 98%.

A major contributor to low overall efficiency is scrubber maintenance, where the scrubber must be by-passed to facilitate repair or cleanout. This can be overcome by installing extra modules and transferring the load.

ENVIRONMENTAL PROBLEMS

The limestone slurry process may create environmental problems in the following areas:

1. Large quantities of waste must be disposed of in an environmentally acceptable manner.
2. Stack emissions may create an "acid rain" under certain weather conditions if reheat is not provided.
3. Low scrubber availability may increase the overall SO_2 emissions, if alternate control facilities or methods are not provided.

NOTES

A. The scrubbers which can be used in this process are described in detail in sections 1.4.2 to 1.4.10

B. Mitsubishi adds gypsum "seed" crystals to the absorption slurry to provide seed sites for the $CaSO_4$ crystallation. This helps prevent scaling. They also use sulfuric acid in the oxidizer to ensure the proper pH for reaction, and to guarantee complete conversion.

C. The cost data include amortized capital investments, overhead, utilities, raw materials, labor and maintenance; but do not include by-product credits, or fixation costs.

MANUFACTURER/SUPPLIER

Babcock & Wilcox Co.
Chiyoda Chemical Engineering and
  Construction Co., Ltd.
Combustion Engineering, Inc.
Environeering Inc., Division of
  Riley Stoker
Envirotech Corp., Chemico Air
  Pollution Control Division
Mitsubishi Heavy Industries, Ltd.
Peabody Air Resources, Inc.
Pullman Kellogg, Division of Pullman, Inc.
Research Cottrell, Industrial Division
Tennessee Valley Authority
UOP Inc., Air Correction Division
Zurn Industries, Inc.

REFERENCES

1. "Proceedings: Symposium on Flue Gas Desulfurization, New Orleans, March 1976, Volume 1", U.S. Environmental Protection Agency, EPA 600/2-76-136a, (May 1976).
2. Federal Power Commission, "The Status of Flue Gas Desulfurization Applications in the United States: A Technological Assessment", A staff report of the Bureau of Power, July 1977.
3. Electric Power Research Institute, "Evaluation of Regenerable Flue Gas Desulfurization Process", EPRI FP-272, Volumes 1 and 2 (January 1977).

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Gas Treatment	Liquid Scrubbers/Contactors (Absorption Processes)

SPECIFIC DEVICE OR PROCESS	NUMBER
Fly Ash Alkali Process	1.4.1.3

POLLUTANTS CONTROLLED		AIR				WATER				LAND			
		GASES		PARTICULATES		DISSOLVED		SUSPENDED		LEACHABLE		FUGITIVE	
	ORGANIC												
x	INORGANIC	x	SO2	x	fly ash								
	THERMAL												
	NOISE												

PROCESS DESCRIPTION

The fly ash alkali process is a nonregenerative, throwaway flue gas desulfurization (FGD) process. This process, shown in Figure 1, uses the alkaline content of the coal's fly ash to remove SO_2 from the flue gas. Lime or limestone is used as a suppliment in case the fly ash alkali is insufficient for SO_2 removal. Flue gas from the boiler is contacted with recycle water (PH=2.8-4.5) in a venturi scrubber.[A] Here the fly ash is removed and the alkaline content, consisting of compounds such as Na_2O, MgO and CaO, is leached out. SO_2 is absorbed in the recycle liquor and oxidized to form sulfuric acid; very little sulfurous acid is formed. Sulfuric acid in turn reacts with the hydrated alkaline species according to the following reactions.

$$Ca(OH)_2 + H_2SO_4 \longrightarrow CaSO_4 \cdot 2H_2O \qquad (1)$$

$$Mg(OH)_2 + 5H_2O + H_2SO_4 \longrightarrow MgSO_4 \cdot 7H_2O \qquad (2)$$

$$2NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O \qquad (3)$$

Clean gas from the scrubber is passed through a mist eliminator and can be reheated to 175°F (90°C) before discharge. Fly ash removed in the scrubber settles out in the bottom of the scrubber and is pumped as a slurry to the thickener. Slaked lime or fine ground limestone is added to react with any residual SO_2 and to adjust the pH for scale prevention. Thickener sludge is disposed of in a pond (section 4.1), or dewatered, fixed and disposed of in a landfill (sections 2.5, 3.1 and 1.3 respectively). Overflow from the thickener is recycled to the scrubber.

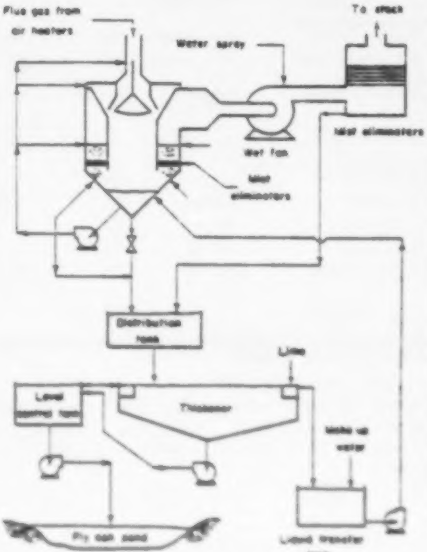


Figure 1. FLY ASH ALKALI/LIME PROCESS

The fly ash alkali process, because of its simplicity is very easy to retrofit to existing plants. However, scaling and low efficiency may be a problem.

As an alternate to the process shown in Figure 1, fly ash can be removed in an electrostatic precipitator and stored for use in the FGD process. In this case, both lime and fly ash would be added to the thickener. This system can be easily applied to existing plants which have dust removal systems already in operation. With the fly ash being removed in a separate system, a more efficient absorber can be used to increase SO_2 removal efficiencies.[B]

APPLICATION RANGE

The fly ash alkali process is a highly effective way to eliminate a fly ash disposal problem when the fly ash has no commercial value and has a high alkaline content. Fly ash produced from western coals usually has a high alkalinity. This process is ideal for remote plants where access to alternate alkali sources is difficult. Large storage areas are not required for raw materials and less area is required for ponding and disposal as compared to other throwaway processes.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	kPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Capital costs vary a great deal depending upon the coal characteristics (sulfur, ash, and calcium content) and upon the system characteristics (dust collection and disposal systems.) A summary of the installed costs for commercial plants currently in operation is shown below.[3]

CAPITAL COSTS

Utility	Scrubber Vendor	Total Capacity (MW)	Startup Date	Installed Cost ($/kw)
Arizona Public Service Co. • Four Corners Plant	Chemico	575	Jan. 1972	52
Minnkota Power Cooperative • Milton R. Young	Combustion Equip. Assoc.	450	Sep. 1977	71.11
Minnesota Power & Light • Aurora Station	Krebs Engineers	116	June 1971	--
• Clay Boswell Plant	Krebs Engineers	350	May 1973	--
Montana Power Co. • Colstrip Station	Combustion Equip. Assoc.	720	July 1976	83.74
Pacific Power & Light • Dave Johnston Plant	Chemico	330	April 1972	24*
Public Service Co. of Colorado • Valmont Station	UOP, Inc.	196	Nov. 1971	32
• Cherokee #1	UOP, Inc.	115	June 1973	33
• Cherokee #3	UOP, Inc.	170	Nov. 1972	29
• Cherokee #4	UOP, Inc.	375	July 1974	33
• Arapahoe Station	UOP, Inc.	112	Sep. 1973	41

-- Data Not Available
* Does not include costs incurred in startup.

OPERATING COSTS

Operating costs vary a great deal depending upon the scrubber characteristics, supplimental lime usage, and various utility requirements. Operating requirements for a number of commercial plants are shown below.[3]

OPERATING REQUIREMENTS

Utility	Lime (ton/day)	Water (acre ft./yr)	Power*	Steam (lb/hr: psi)	Manpower
Arizona Public Service Co. • Four Corners Plant	6	3800	3-4 %	--	8 operators
Minnesota Power & Light • Aurora Station	0	3500	0.8 %	0	--
Clay Boswell Plant	0	2300	0.86%	0	--
Pacific Power & Light • Dave Johnston Plant	Lime plus Lignosulfonate	1600	2.1 %	--	--
Public Service Co. of Colorado • Valmont Station	0	340	5.4 %	50,000: 490	--
• Cherokee #1	0	327	4.5 %	56,000: 350	--
• Cherokee #3	0	612	3.9 %	41,200: 305	--
• Cherokee #4	0	1200	3.8 %	125,000: 1,975	--
• Arapahoe Station	0	327	4.6 %	84,250: 150	--

-- Data Not Available
* Power is shown as % of net generating capacity.

OPERATING EFFICIENCIES

The operating efficiency for the fly ash alkali process is sensitive to the coal properties, especially the calcium content. Particulate and SO_2 removal efficiencies for several commercial plants are presented below.[C]

OPERATING EFFICIENCY

Utility	Particulate (%)	SO_2 (%*)	Availability (%)	Reported Cost (mills/kwh)
Arizona Public Service Co. • Four Corners Plant	99.2	30-35	60	--
Minnkota Power Cooperative • Milton R. Young	99.6	75	--	--
Minnesota Power & Light • Aurora Station	96.2	25	--	--
• Clay Boswell Plant	97.5	15-20	--	--
Montana Power Co. • Colstrip Station	99.5	72-75	63-100	3.26
Pacific Power & Light • Dave Johnston Plant	99+	35-40	--	--
Public Service Co. of Colorado • Valmont Station	--	45-50	85	--
• Cherokee #1	--	15-[illegible]	53	--
• Cherokee #3	--	11-35	86	3.10
• Cherokee #4	--	11-20	47	--
• Arapahoe Station	--	45-50	64	--

-- Data Not Available
* SO_2 efficiency is shown for operation without lime addition.

ENVIRONMENTAL PROBLEMS

The fly ash alkali process may create environmental problems in the following areas:

1) Substantial quantities of waste must be disposed of in an environmentally acceptable manner.

2) Stack emissions may create an "acid rain" under certain weather conditions if reheat is not provided.

3) Low scrubber availability may increase the overall SO_2 emissions, if alternate control facilities or methods are not provided.

NOTES

A) A variety of other scrubbers could be used depending upon the inlet conditions. Only the manufactures listed below have scrubbers operating on a commercial scale at the present.

B) Scrubbers which require external particulate removal can be used in this situation without plugging.

C) Some scrubbers are used primarily for particulate scrubbing. The efficiencies of these scrubbers could be increased by adding more lime to the system. Source: See Reference 3.

MANUFACTURER/SUPPLIER

Combustion Engineering, Inc.
Combustion Equipment Asociates
Envirotech Corp., Chemico Air
  Pollution Control Division
Krebs Engineers, Gas Kinetics Division
Peabody Air Resources Inc.
UOP Inc., Air Correction Division

REFERENCES

1) Noll, Kenneth E., and Davis, Wayne T., ed., Power Generation: Air Pollution Monitoring and Control, Ann Arbor Science Publishers Inc., Ann Arbor, Mich., (1976).
2) Federal Power Commission, "The Status of Flue Gas Desulfurization Applications in the United States: A Technological Assessment", A staff report of the Bureau of Power, (July 1977).
3) "Proceedings: Symposium on Flue Gas Desulfurization; New Orleans, March 1976, Volume 1," EPA 600/2-76-136a, (May 1976).

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Gas Treatment	Liquid Scrubbers/Contactors (Absorption Processes)

SPECIFIC DEVICE OR PROCESS	NUMBER
Aqueous Sodium Process	1.4.1.4

POLLUTANTS CONTROLLED		AIR				WATER				LAND			
		GASES		PARTICULATES		DISSOLVED		SUSPENDED		LEACHABLE		FUGITIVE	
☐	ORGANIC	☐		☐		☐		☐		☐		☐	
x	INORGANIC	x	SO_2	x	fly ash	☐		☐		☐		☐	
☐	THERMAL												
☐	NOISE												

PROCESS DESCRIPTION

The aqueous sodium process uses a solution of sodium carbonate or sodium hydroxide to remove SO_2 from flue gases. The sodium carbonate can be obtained from raw trona (~ 60% sodium carbonate equivalent), from commercial soda ash or from a waste liquor containing soda ash. Sodium hydroxide can be obtained from a waste caustic stream or purchased. The latter is the most expensive source of the alkali. This process shown in Figure 1, is the simplest and most reliable of the nonregenerable throwaway FGD processes.

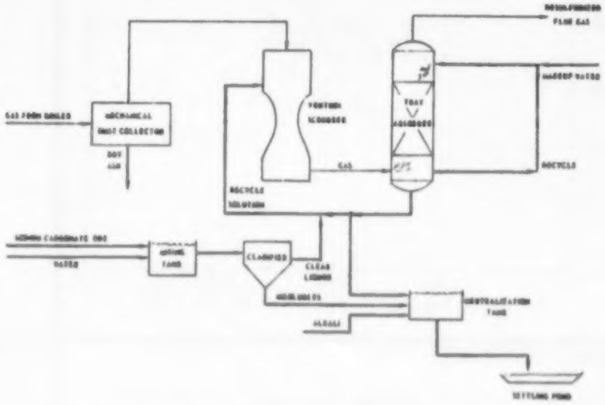


Figure 1. AQUEOUS SODIUM PROCESS

Hot flue gas from the boiler passes through a mechanical type dust collector (shown) or an electrostatic precipitator to remove most of the fly ash (75%+). The gas then enters a venturi scrubber which contacts the gas with an aqueous sodium solution. Here the remaining fly ash and some of the SO_2 is removed according to reactions (1) or (2). The residual SO_2 is abosorbed in a tower containing a single sieve tray. Gas from the tower is

$$Na_2CO_3 + SO_2 \longrightarrow Na_2SO_3 + CO_2 \qquad (1)$$

$$2NaOH + SO_2 \longrightarrow Na_2SO_3 + H_2O \qquad (2)$$

passed through a mist eliminator and disposed of by tall stacks. The clean flue gas can also be reheated to eliminate a visible plume, to reduce ambient SO_2 concentrations and to eliminate "acid rain" in cold weather.

Trona is mixed with water and the solution is clarified to remove inert materials contained in the ore. Sodium carbonate under certain conditions may crystallize out of concentrated solutions plugging pumps and piping. Downtime because of these "frozen" lines can be averted by operating at reduced concentrations or by heat traced piping. Waste liquor from the scrubber recycle system is continuously bled off (~ 5%) and neutralized before disposal in a lined pond (section 4.1). As an alternative, the disposal solution can be oxidized by aeration to form sodium sulfate (Na_2SO_4). This solution, with no oxygen demand, can then be disposed, treated, or evaporated to produce by-product sodium sulfate.

Krebs Engineers produces a scrubber system in which untreated flue gas is treated countercurrently with a sodium-based scrubbing liquor. Fly ash, removed in the first stages, is washed in a countercurrent decantation system and sent to a disposal pond. Sodium sulfate is crystallized from the scrubbing liquor and sold as a by-product. See 1.4.2.3 for details on the Krebs Elbair Scrubber.

In general the aqueous sodium process is far superior to other nonregenerable throwaway processes because their is no possibility for calcium scaling and associated downtime, corrosion and erosion are greatly reduced if not eliminated, and the SO_2 removal efficiency is much greater, approaching 99% in some cases.

APPLICATION RANGE

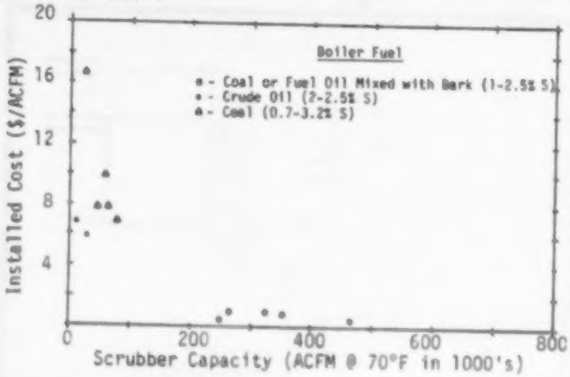
OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	kPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

The aqueous sodium process is especially applicable to utility boiler applications where low SO_2 and particulate emissions are required. It is also well suited to industrial applications, especially those that currently produce a waste effluent containing caustic or soda ash in significant quantities.

At present there are 56 scrubbers operating commercially on industrial boilers, totaling an equivalent of 968 MW. In addition, 3 utility boilers (totaling 325 MW) use the aqueous sodium process. Flows vary from 8000 to 723,000 SCFM. SO_2 concentrations are reported to range between 150 to 2000 ppm, although higher concentrations could be efficiently handled.

CAPITAL COSTS

The capital cost for the aqueous sodium process vary a great deal depending upon the size, fuel type, and scrubber vendor. Capital costs of existing industrial boilers are shown below for 3 types of boiler fuels[3]. Nevada Power Co. is the only utility currently operating a sodium carbonate scrubber. It has reported a $44/kW installed cost for 2 units rated at 125 MW each[2].



OPERATING COSTS

Operating costs depend a great deal upon the source and the cost of the alkali. Three industrial plants have reported operating costs ranging from 1.009 to 1.361 $/SCFM[3]. Nevada Power Co. their annual operating costs as $1.2 million, (0.83 $/SCFM[2]). The cost includes $600,000 amortized capital for both units.

OPERATING EFFICIENCIES

SO_2 removal efficiencies have been reported for both utility and industrial applications. Industrial application range from 80-95%[3]. Nevada Power Co., the only utility using the aqueous sodium process has reported 85% SO_2 removal efficiencies for all three Reid Gardner units.

Particulate efficiencies vary depending upon dust loadings and auxiliary dust removal systems. In general, all systems reported particulate efficiencies of 80-90%.

ENVIRONMENTAL PROBLEMS

The aqueous sodium process may create environmental problems in the following areas:

1. Large quantities of scrubber liquor must be disposed of in an evaporation pond, or be treated prior to discharge from the plant.
2. Stack emissions may create an "acid rain" under certain weather conditions and increase ground level SO_2 concentrations if reheat is not provided.

NOTES

A. Various other scrubber types can be used in this process. Only the manufacturers listed below have scrubbers in commercial operation.

MANUFACTURER / SUPPLIER

Air Pollution Industries, Inc.
Ceilcote Co., The, A Division of General Signal
Combustion Equipment Associates, Inc.
Entoleter, Inc., Sub. of American Mfg. Co.
FMC Corp.
Flakt, Inc.
Great Western Sugar Co.
Krebs Engineers, Gas Kinetics Division
Arthur D. Little, Inc.
Mobil Oil Corp.
Peabody Engineering Corp.
W. W. Sly Manufacturing Co., The
Swemco Inc.

REFERENCES

1) Federal Power Commission, "The Status of Flue Gas Desulfurization Applications in the United States: A Technological Assessment", A staff report of the Bureau of Power, (July 1977).
2) "Summary Report - Utility Flue Gas Desulfurization Systems - October - November 1977", prepared by Ped Co Environmental Inc., under EPA Contract 68-01-4147, Task 3.
3) Tuttle, J., Patkar, A., and Gregory, N., "EPA Industrial Boiler FGD Survey: First Quarter 1978", EPA 600/7-78-052a, (March 1978).

CLASSIFICATION Gas Treatment	**GENERIC DEVICE OR PROCESS** Liquid Scrubbers/Contactors (Absorption Processes)
SPECIFIC DEVICE OR PROCESS Aqueous Ammonia Process	**NUMBER** 1.4.1.5

POLLUTANTS CONTROLLED		AIR				WATER				LAND			
		GASES		**PARTICULATES**		**DISSOLVED**		**SUSPENDED**		**LEACHABLE**		**FUGITIVE**	
☐	**ORGANIC**	☐		☐		☐		☐		☐		☐	
x	**INORGANIC**	x	SO_2	x	fly ash	☐		☐		☐		☐	
☐	**THERMAL**												
☐	**NOISE**												

PROCESS DESCRIPTION

The aqueous ammonia process uses a solution of ammonium sulfate ($(NH_4)_2SO_4$), ammonium sulfite ($(NH_4)_2SO_3$), ammonium bisulfite (NH_4HSO_3), and ammonium hydroxide (NH_4OH) to remove particulate and SO_2 from boiler flue gases. The process was developed by replacing the water in a particulate scrubber with ammonia laden process water. SO_2 is readily absorbed and reacts with the ammonium salts according to reaction 1,2 and 3. SO_2 can be oxidized to form SO_3 which reacts similarly to form

$$(NH_4)_2\,SO_3 + SO_2 + H_2O \longrightarrow 2NH_4HSO_3 \qquad (1)$$

$$2NH_4OH + SO_2 \longrightarrow (NH_4)_2SO_3 + H_2O \qquad (2)$$

$$NH_4HSO_3 + NH_4OH \longrightarrow (NH_4)_2SO_3 + H_2O \qquad (3)$$

$$(NH_4)_2SO_3 + 1/2\ O_2 \longrightarrow (NH_4)_2SO_4 \qquad (4)$$

$(NH_4)_2SO_4$ or the ammonium sulfite can be oxidized to the sulfate form as shown in reaction 4.

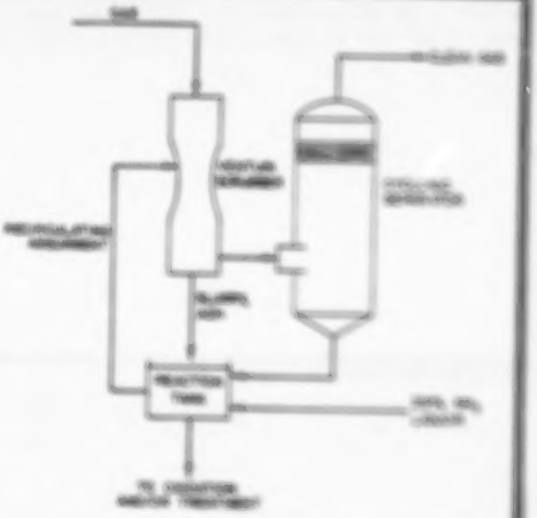


Figure 1. AQUEOUS AMMONIA PROCESS

Figure 1 illustrates this process as it is presently used. Gas is contacted with recirculating absorbent in a venturi scrubber. Entrained solution is removed in a cyclonic separator equipped with a mesh or chevron type mist eliminator. Scrubber liquor from the venturi and the separator is combined in a reaction tank where the pH is adjusted with fresh ammonia liquor. The pH is a critical control parameter because a low pH produces a dense "blue" plume due to the gas phase reaction of SO_2 and ammonia. Catalytic, Inc. has done a considerable amount of research in plume formation and have patented criteria used to prevent plume formation, (U.S. Patent [illegible], 197[illegible]). A high efficiency mist eliminator can be used if the "blue" plume cannot be adequately controlled by pH. Stack gas reheat can be used to eliminate the water vapor plume normally associated with wet FGD processes.

A bleed stream is removed from the reaction tank to maintain a constant water balance. This stream can be oxidized and filtered to form a pure ammonium sulfate fertilizer for resale as a solution or after crystallization. Most plants currently dispose of this solution, reuse it or send it to an inplant water treatment facility.

Another option to the process shown in Figure 1 is to add an absorber after the separator to increase SO_2 removal efficiency. This unit could be a spray scrubber, packed tower or a plate tower (sections 1.4.2, 1.4.7 and 1.4.8 respectively). A variety of recirculation configurations can be used with these scrubbers to increase SO_2 removal efficiency and to reduce plume formation. Other regenerable processes are being developed to produce by-products such as SO_2 (ABS Process[illegible]), or elemental sulfur (Catalytic/IFP Ammonia Scrubbing Process[illegible]).

APPLICATION RANGE

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	kPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

The aqueous ammonia process is well suited to boiler applications where an ammoniacal waste stream is available at low cost. A higher cost ammonia source could be used if the by-products can be marketed[illegible]. Seven industrial boiler applications are currently in operation on a commercial scale. These applications are all sugar plants, which generate ammoniacal waste streams. The flow rates for the scrubbers in these plants range from 25,000 to 191,000 ACFM @ 70°F[illegible]. SO_2 concentrations at the scrubber inlets range from [illegible] to [illegible] ppm. The regenerable processes have been used in sulfite paper mills and sulfuric acid plants for years on effluents containing 8000 to 20,000 ppm SO_2.

CAPITAL COSTS

There are currently seven industrial installations of the aqueous ammonia process. Only one of these plants has reported capital costs. There are no commercial utilities using the process.

The Minn-Dak Farmer's Cooperative has installed two variable throat venturi scrubbers and a single cyclonic separator at their Wahpeton, N.D. sugar plant. Two boilers generate 125,000 ACFM @ 350°F each. The installed cost for this system was $300,000 in 1977 dollars. The boilers burn 1% S lignite and each produce 275,000 lbs/hr steam at 250 psig and 455°F[1].

OPERATING COSTS

No operating costs have been reported for the aqueous ammonia process. The bleed stream which would require treatment varies from plant to plant. The flow range has been reported to be from 160 to 800 gpm. The ammonia requirement in most cases will be approximately equal to the stoichiometric amount required to react with the SO_2. This quantity can be reduced considerably for the regenerable processes.

OPERATING EFFICIENCIES

All seven installations of the aqueous ammonia process were designed primarily for particulate control. The Great Western Sugar plants (6 total) have experienced SO_2 removal efficiencies of 35% for inlet concentrations ranging from 300 to 400 ppm SO_2. The Minn-Dak Farmer's Cooperative has reported inlet loadings of 76-193 lbs/hr SO_2. These have been reduced to 10-37 lb/hr SO_2 at the scrubber outlet.

In general, the scrubber manufacturers believe SO_2 removal efficiencies of up to 95% can be obtained with the addition of the absorber or with either of the regenerative processes.

ENVIRONMENTAL PROBLEMS

The aqueous ammonium process may create environmental problems in the following areas:

1) Large quantities of scrubber liquor must be disposed of or treated if ammonium sulfate is not sold as fertilizer.
2) A dense "blue" plume may be created if the operating conditions are not precisely controlled. In addition, with low efficiencies an "acid rain" may be created under certain weather conditions and ground level SO_2 concentrations may be unacceptable if reheat is not provided.

NOTES

A) Ammonium Bisulfate (ABS Process) was developed by the EPA and the TVA.
B) Developed by Catalytic, Inc., subsidiary of Air Products and Chemicals, and the Institut Francais du Petrole.
C) The ammonium sulfate fertilizer market in the U.S. may be questionable.
D) The largest plant actually has two scrubbers totaling 382,000 ACFM @ 70°F.

MANUFACTURER / SUPPLIER

Catalytic, Inc.
Koch Engineering Co., Inc.
Nippon Kokan KK
Research Cottrell, Industrial Division
Swemco, Inc.

REFERENCES

1) Tuttle, J., Patkar, A., and Gregory, N., "EPA Industrial Boiler FGD Survey: First Quarter 1978", EPA 600/7-78-052a, (March 1978).
2) Electric Power Research Institute, "Evaluation of Regenerable Flue Gas Desulfurization Process", EPRI FP-272 Volumes 1 and 2 (January 1977).
3) Noll, Kenneth E., and David, Wayne T., ed., Power Generation: Air Pollution Monitoring and Control, Ann Arbor Science Publishers Inc., Ann Arbor, Mich., (1976).

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Gas Treatment	Liquid Scrubbers/Contactors (Absorption Processes)

SPECIFIC DEVICE OR PROCESS	NUMBER
Double Alkali Process	1.4.1.6

POLLUTANTS CONTROLLED		AIR		WATER		LAND	
		GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
☐	ORGANIC	☐	☐	☐	☐	☐	☐
X	INORGANIC	x SO_2	x fly ash	☐	☐	☐	☐
☐	THERMAL						
☐	NOISE						

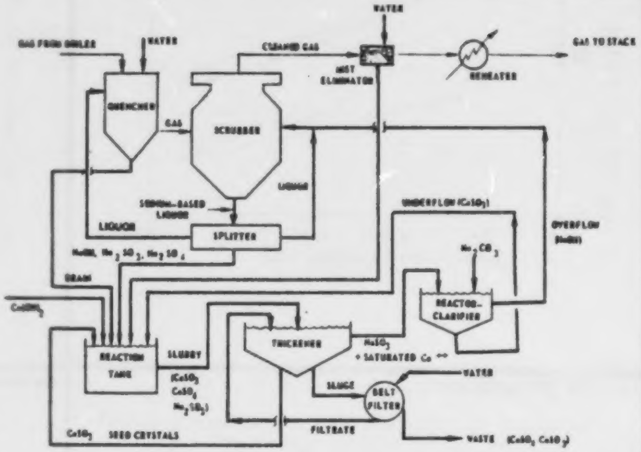


Figure 1. DOUBLE ALKALI PROCESS

PROCESS DESCRIPTION

The double alkali process is the most widely used regenerable FGD system currently applied on a commercial scale in the United States. The process, shown in Figure 1, uses a sodium hydroxide (NaOH)/sodium sulfite (Na_2SO_3) solution to cool the gas and to absorb SO_2[A]. SO_2 absorbed in the liquor reacts with the sodium compounds according to reaction 1 and 2. Sodium sulfate (Na_2SO_4) and other sulfate compounds can also be formed by the oxidation of any of the sulfur species. Clean gas from the scrubber is passed through a mist eliminator and is reheated prior to discharge.

$$2\ NaOH + SO_2 \rightarrow Na_2SO_3 + H_2O \quad (1)$$

$$Na_2SO_3 + SO_2 + H_2O \rightarrow 2\ NaHSO_3 \quad (2)$$

Scrubbing liquor from the recycle system containing sodium salts and possibly some unreacted sodium hydroxide is combined with other effluents and sent to the regeneration section of the plant. Here the liquor is reacted with lime or limestone to precipitate sulfur compounds and to restore the alkaline content of the liquor for recycle. Lime reacts with sulfite in the liquor according to reactions 3 and 4, and limestone according to reaction 5. Sulfate reacts in a similar manner. The concentrations of sulfate in solution is dependent upon the degree of sulfite oxidation. However, because of the solubility relationship, the concentration of sulfate at steady state rises sharply for relatively small increases in oxidation. If the relative oxidation of sulfite exceeds 15-25%, the concentration of sulfate will be too high for efficient operation. This can be corrected by purging solution or by increasing the pH with lime[B] to precipitate gypsum (similar to reaction 4). Systems which have high oxidation and require regeneration to NaOH (low concentrations of Na_2SO_3) are called "dilute". Those systems which have low oxidation and regenerate to Na_2SO_3 are termed "concentrated". Concentrated systems usually have an active sodium (Na^+ associated with SO_2 absorption) concentration greater than 0.15M.

$$Ca(OH)_2 + 2\ NaHSO_3 \rightarrow Na_2SO_3 + CaSO_3 \cdot 1/2\ H_2O\downarrow + 3/2\ H_2O \quad (3)$$

$$Ca(OH)_2 + Na_2SO_3 + 1/2\ H_2O \rightarrow 2\ NaOH + CaSO_3 \cdot 1/2\ H_2O\downarrow \quad (4)$$

$$CaCO_3 + 2\ NaHSO_3 + 1/2\ H_2O \rightarrow Na_2SO_3 + CaSO_3 \cdot 1/2\ H_2O\downarrow + CO_2 + H_2O \quad (5)$$

Precipitated solids are removed from the regenerated liquor in a clarifer. Some of the solids are recycled back to the regeneration section to reduce the possibility for scaling in the reaction tank. The recycle liquor for the dilute system contains a considerable amount of calcium, and must be treated with Na_2CO_3 (trona or soda ash), Na_2SO_3 or CO_2 to precipitate the calcium[C]. This softening process eliminates scaling in the scrubber. Solids from the regeneration process are dewatered, washed to recover the alkali content and disposed of in a landfill. The sludge handles substantially different from lime or limestone sludge because it is a granular material and does not require fixation.

An option to the above system is an ammonia based double alkali process. This process is similar to the aqueous ammonia process (1.4.1.5), but the scrubbing solution is regenerated with lime to produce ammonia. This ammonia is collected from the reaction tank and used to generate fresh ammonia liquor for recycle. This process has much of the same advantages and disadvantages as the aqueous ammonia process. However, it is more attractive than the sodium based double alkali process because the ratio of sulfite to sulfate is not critical.

APPLICATION RANGE

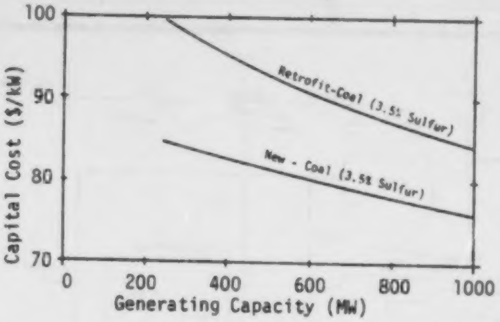
The double alkali process is especially applicable to utility and industrial boilers which require high SO_2 removal efficiencies. It is also well suited to plants with a limited capacity for waste water treatment. However, its application is limited to plants which have an environmentally acceptable sludge disposal system.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

The double alkali process is currently being used on many industrial boilers having flow rates ranging from 10,000 to 640,000 cfm with SO_2 loadings reported from 800 to 2000 ppm. Three utility applications are currently under construction. These range in size from 250 to 575 MW.

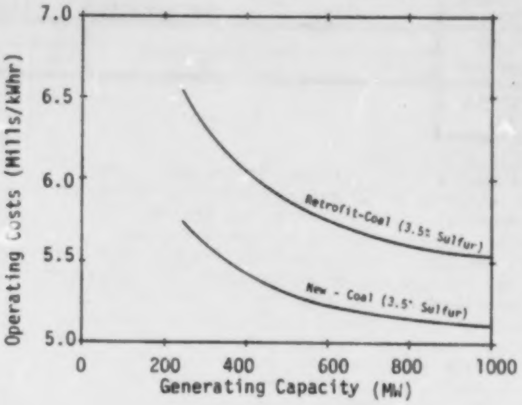
CAPITAL COSTS

Capital costs for the double alkali process, as reported by PedCo Environmental, have ranged from 2.46 to 23.2 $/CFM @ 70°F for industrial applications and from 43.2 to 189.0 $/kW for utilities. PedCo also prepared a cost estimate for the EPA in June of 1976. This data is presented below[D].



OPERATING COSTS

Operating costs for current installations of the double alkali process are not available. PedCo Envir-Environment completed a cost estimate for the EPA in June 1976. This cost information is shown below[D].



OPERATING EFFICIENCIES

The operating efficiencies for the double alkali process, similar to the aqueous sodium process (1.4.1.4), are very high compared to the lime or limestone processes (1.4.1.1, 1.4.1.2). Systems can be designed for removal efficiencies in excess of 90% because the sodium alkali scrubbing agent is very reactive. Availability of the double alkali process has been reported to be greater than 90% in most installations.

ENVIRONMENTAL PROBLEMS

The double alkali process may create environmental problems in the following areas:

1) Large quantities of waste must be disposed of in an environmentally acceptable manner.

2) Stack emissions may create an "acid rain" under certain weather conditions if reheat is not provided.

NOTES

A) The ratio of NaOH to Na_2SO_3 is dependent upon pH. The higher the pH, the more NaOH is present.

B) With lime the system can be operated over a wider pH range than with limestone.

C) The concentrated system has a high concentration of Na_2SO_2 which prevents high calcium concentrations. Thus the reactor clarifier is not needed.

D) Source: Green, R., "Utilities Scrub Out SO_x", Chemical Engineering, Vol. 84, No. 11, (May 23, 1977).

MANUFACTURER / SUPPLIER

Combustion Equipment Associates
Envirotech Corp., Chemico Air Pollution Control Division
FMC Corp.
Koch Engineering Co., Inc.
Krebs Engineers, Gas Kinetics Division
Little, Arthur D., Inc.
Nippon Kokan KK
Zurn Industries, Inc.

REFERENCES

1) Federal Power Commission, "The Status of Flue Gas Desulfurization Applications in the United States: A Technological Assessment", A staff report of the Bureau of Power, (July 1977).
2) "Proceedings: Symposium on Flue Gas Desulfurization; New Orleans, March 1976, Volume 1", EPA 600/2-76-136a, (May 1976).
3) Rochelle, G. T., King, C. J., "Alternatives for Stack Gas Desulfurization by Throwaway Scrubbing", Chemical Engineering Progress, Vol. 74, No. 2, (February 1978).

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Gas Treatment	Liquid Scrubbers/Contractors (Absorption Processes)

SPECIFIC DEVICE OR PROCESS	NUMBER
Magnesium Oxide Process	1.4.1.7

POLLUTANTS CONTROLLED		AIR			WATER				LAND			
		GASES		PARTICULATES	DISSOLVED		SUSPENDED		LEACHABLE		FUGITIVE	
☐	ORGANIC	☐		☐		☐		☐		☐		☐
☒	INORGANIC	☒	SO_2	☒	fly ash	☐		☐		☐		☐
☐	THERMAL											
☐	NOISE											

PROCESS DESCRIPTION

The magnesium oxide process, shown in Figure 1, is a regenerable flue gas desulfurization process currently being used exclusively on utility boilers. Flue gas is treated in an electrostatic precipitator to remove most of the fly ash. The remaining fly ash is removed in the first stage wet scrubber. Here, the gas is cooled and humidified by direct contact with recycle water in a venturi scrubber. Fly ash is removed from the recycle water by a thickener and disposed of in a landfill.

Particulate free flue gas is next contacted with magnesium oxide slurry in another venturi scrubber[A]. The reaction of MgO with water is shown in reaction 1. SO_2 is absorbed and reacts according to reaction 2. SO_2 in the flue gas can be oxidized to form SO_3 which

$$MgO + H_2O \longleftrightarrow Mg(OH)_2 \qquad (1)$$

$$Mg(OH)_2 + SO_2 + 2\ H_2O \longrightarrow MgSO_3 \cdot 3\ H_2O + \qquad (2)$$

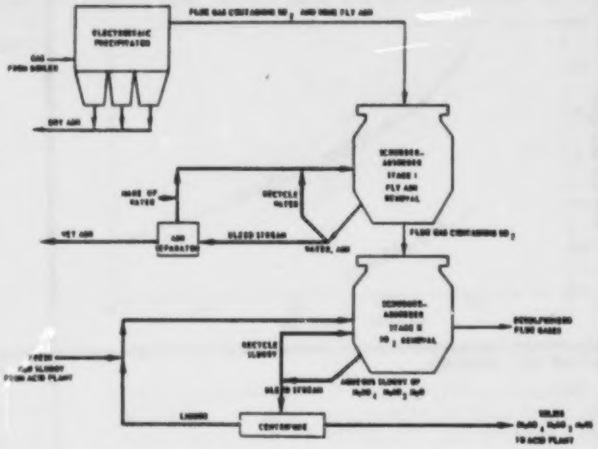

FLUE GAS CONTAINING SO2 AND SOME FLY ASH
ELECTROSTATIC PRECIPITATOR
GAS FROM BOILER
DRY ASH
SCRUBBER-ABSORBER STAGE I FLY ASH REMOVAL
MAKE UP WATER
RECYCLE WATER
WET ASH
ASH SEPARATOR
BLEED STREAM
WATER, ASH
FLUE GAS CONTAINING SO2
SCRUBBER-ABSORBER STAGE II SO2 REMOVAL
DESULFURIZED FLUE GASES
FRESH MgO SLURRY FROM ACID PLANT
RECYCLE SLURRY
BLEED STREAM
AQUEOUS SLURRY OF MgSO3, MgSO4, MgO
LIQUID
CENTRIFUGE
SOLIDS MgSO3, MgSO4, MgO TO ACID PLANT

Figure 1. MAGNESIUM OXIDE PROCESS

reacts similar to reaction 2 to form $MgSO_4$. Cleaned flue gas from the absorber is reheated and disposed of through tall stacks. A bleed stream is removed from the magnesium oxide recycle system, centrifuged and dried to remove the water of hydration[B]. The dried crystals containing magnesium sulfite, sulfate and some unreacted oxide are usually sent to a sulfuric acid plant (not shown) for regeneration to MgO and SO_2[C]. In regeneration, accomplished thermally (1800-2200°F) in a rotary kiln, magnesium sulfite reacts according to reaction 3. Coke is added to reduce the sulfate; this is

$$MgSO_3 \xrightarrow{heat} MgO + SO_2 \qquad (3)$$

$$MgSO_4 + 1/2\ C \xrightarrow{heat} MgO + SO_2 + 1/2\ CO_2 \qquad (4)$$

shown in reaction 4. The SO_2 generated here can be used to produce sulfuric acid or elemental sulfur. The MgO is recycled to the absorption section of the plant. By maintaining larger inventories of MgO, extended outages of the regeneration facility can be tolerated. If another company or plant is used for regeneration, care must be taken to insure the long term availability of these facilities before the MgO process is considered. Many plants have been built only to discover the regeneration facilities have discontinued service.

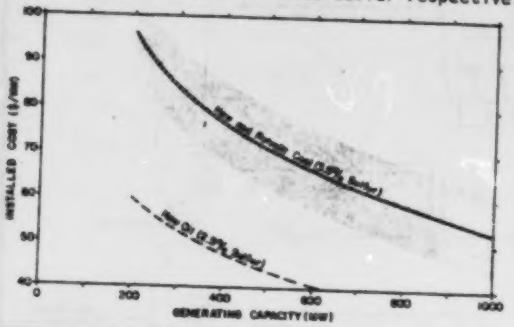
APPLICATION RANGE

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

The magnesium oxide process can be used to remove SO_2 from boiler flue gases and other combustion sources. Particulate removal is provided for with a separate scrubber. The process has been applied to smelter off-gases, sulfuric acid plant effluents, Claus plant effluents and utility boiler flue gases. However, the experience with coal fired boilers may be somewhat limited. Industrial applications have ranged in size from 28 to 162 MW equivalent with SO_2 loadings from 1,500 to 25,000 ppm. Utilities, planned and operating, range in size from 95 to 336 MW.

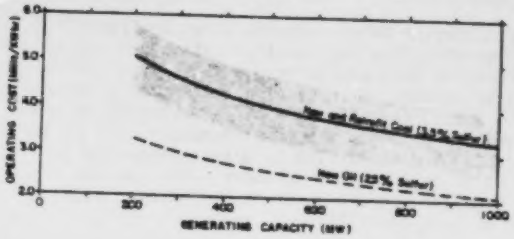
CAPITAL COSTS

Capital costs for the magnesium oxide process are not available for industrial applications. Philadelphia Electric has reported[3] the capital cost for their 120 MW application at $90/kW. Costs were estimated by EPA/TVA for a startup in mid-1978. These costs are shown below[2]. The costs shown are installed costs and are based on a 90% SO_2 removal efficiency. All costs are dependent upon the sulfur content of the fuel; the cost variance for FGD systems on new coal fired boilers is shown by the shaded area. The upper and lower limits correspond to 5.0 and 2.0% sulfur respectively.



OPERATING COSTS

Operating costs for the magnesium oxide process are not available for industrial applications. Philadelphia Electric has reported[3] the operating cost for their 120 MW application at 4.7 mills/kWhr. Costs were estimated by EPA/TVA using 1978 cost information. These costs are shown below[2]. The costs shown are total operating costs[D] and are based upon a 90% SO_2 removal efficiency. All costs are dependent upon the sulfur content of the fuel; the cost variance for FGD systems on new coal fired boilers is shown by the shaded area. The upper and lower limits correspond to 5.0 and 2.0% sulfur respectively. Costs include the production of 98% sulfuric acid.



OPERATING EFFICIENCIES

Operating efficiencies for the magnesium oxide process are usually higher than lime or limestone systems despite the similarity in chemistry. This is due to the increased reactivity of the MgO over lime or limestone. Boston Edison and Potomac Electric and Power have reported efficiencies of 90%. Industrial applications have reportedly ranged from 90 to 99.5%.

Past installations have exhibited relatively low reliability performance (low availabilities). Frequent equipment and processing problems have been encountered. However, this should be improved with time due to the low potential for scaling with MgO as compared to lime or limestone systems.

ENVIRONMENTAL PROBLEMS

There are relatively few environmental problems with the magnesium oxide process since the scrubbing reagent is completely regenerated to MgO and SO_2. There may be problems, however, in the following areas:

1) Environmental problems associated with by-product sulfuric acid production.
2) Stack emissions may create an "acid rain" under certain weather conditions if reheat is not provided.

NOTES

A) A variety of other scrubber types can be used (see sections 1.4.2 to 1.4.10).
B) $MgSO_3$ can have three and sometimes six waters of hydration. $MgSO_4$ usually has seven.
C) Regeneration can be carried out on site or at some distance from the absorption system.
D) The cost data include amortized capital investments, overhead, utilities, raw materials, labor and maintenance; but do not include by-product credits.

MANUFACTURER / SUPPLIER

Environeering Inc., Division of Riley Stoker
Envirotech Corp., Chemico Air Pollution Control Division
Research Cottrell, Industrial Division
United Engineers and Constructors, Inc.

REFERENCES

1) Federal Power Commission, "The Status of the Flue Gas Desulfurization Applications in the United States: A Technological Assessment", A staff report on the Bureau of Power, (July 1977).
2) "Proceedings: Symposium on Flue Gas Desulfurization; New Orleans, March 1976, Volume 1 and 2", EPA 600/2-76-136a and b, (May 1976).
3) Pedco Environmental, "Summary Report Utility Flue Gas Desulfurization Systems - Oct. and Nov. 1977", Prepared for U.S. Environmental Protection Agency, Contract 68-01-4147.

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Gas Treatment	Liquid Scrubbers/Contactors (Absorption Processes)

SPECIFIC DEVICE OR PROCESS	NUMBER
Wellman-Lord Process	1.4.1.8

POLLUTANTS CONTROLLED	AIR		WATER		LAND	
	GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
☐ ORGANIC	☐	☐	☐	☐	☐	☐
x INORGANIC	x SO_2	x fly ash	☐	☐	☐	☐
☐ THERMAL						
☐ NOISE						

PROCESS DESCRIPTION

The Wellman-Lord process is a regenerable FGD process which uses a sodium-based alkaline solution for removing SO_2 from combustion gases and other sulfur laden process effluents. The gas stream is treated in a wet scrubber to remove particulate, and to cool and humidify the gas stream (see Figure 1). The wet scrubber discharges directly to an absorber with two or more scrubbing stages. Here SO_2 is absorbed in a sodium sulfite solution according to reaction 1. Reaction 2 shows the oxidation which takes place in the absorber. A considerable amount of the sulfite can be oxidized depending upon the absorber type and the amount of oxygen in the gas stream. The clean flue gas from the absorber is reheated and disposed of through a tall stack.

$$Na_2SO_3 + H_2O + SO_2 \longrightarrow 2\ NaHSO_3 \qquad (1)$$

$$Na_2SO_3 + 1/2\ O_2 \longrightarrow Na_2SO_4 \qquad (2)$$

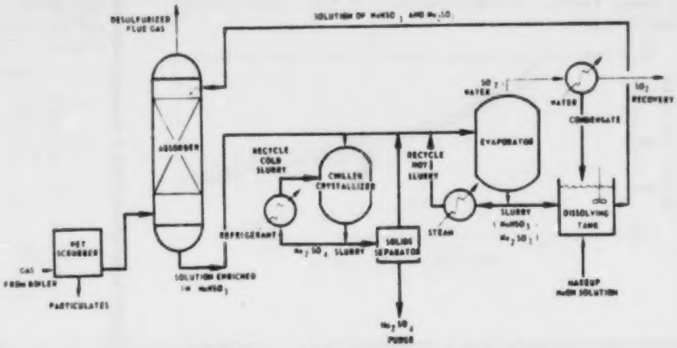


Figure 1. WELLMAN-LORD PROCESS

The sodium sulfite/bisulfite liquor from the absorber is sent to an evaporator with a small bleed stream being sent to a chiller crystallizer for sulfate control. In the crystallizer, the bleed stream is cooled and the sodium sulfate (Na_2SO_4) crystals which form are removed from the slurry and dried for sale or disposal. This method controls the buildup of the nonreactive sulfate ion.

The bulk of the absorber solution is combined with cool sulfite liquor from the sulfate purge section and with hot recycle slurry from the evaporator. This hot slurry is sent to the evaporator[A] where sulfur dioxide and water are driven off according to the reverse of reaction 2. Residual sodium bisulfite is regenerated in a dissolving tank according to reaction 3[B]. This also replaces sodium values list in the sulfate purge. The sodium sulfite solution, containing some sodium bisulfite is recycled to the absorber. The pure sulfur dioxide stream can be used to produce high grade sulfur, sulfuric acid or liquor sulfur dioxide.

$$NaHSO_3 + NaOH \longrightarrow Na_2SO_3 + H_2O \qquad (3)$$

Two systems have been developed by Davy Powergas as alternatives to the sulfate crystallization described above. These systems use either natural gas or coal to chemically reduce the sodium sulfate. The purge stream would thus be regenerated and returned to the process. With either system, chemical make up would be reduced to a minimum and sodium sulfate would not be produced thus eliminating the marketing or disposal problems.

Surge tanks can also be added to the system to store enriched absorber liquor and regenerated solution. This eliminates downtime in the absorber when the regeneration system is down for maintenance. An arrangement like this also will facilitate remote operation of the regeneration system.

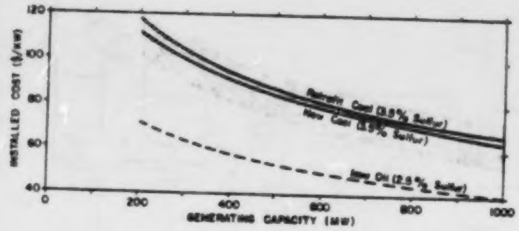
APPLICATION RANGE

The Wellman-Lord process can be applied to any flue gas containing SO_2. It is equally applicable to nonferrous smelters, sulfuric acid plants and Claus plants. The maximum size of a single absorber which Davy Powergas recommends is 300,000 SCFM of flue gas. Larger applications can be handled with multiple units. Current installations of the Wellman-Lord process range in size from 30,000 to 78,000 cfm for sulfuric acid plants, 10,000 to 41,000 cfm for Claus plants, and 89,000 to 435,000 cfm for oil fired boilers. Several coal fired utility boilers are in the planning stages or in construction. These range in size from 250,000 to 2,510,000 cfm. SO_2 loadings have ranged from 900 to 13,000 ppmv.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

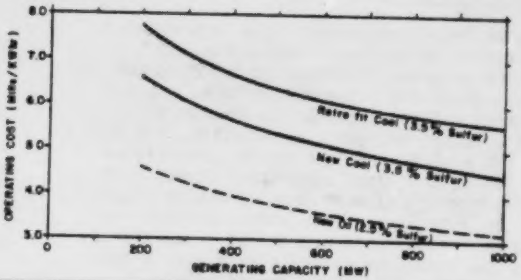
CAPITAL COSTS

Capital costs for the Wellman-Lord process are not available for industrial applications. Northern Indiana Public Service has reported the capital cost for their 115 MW application at \$129/kW[3]. Costs were estimated by EPA/TVA for a startup in mid-1978. These costs are shown below[2]. The costs shown are installed costs and are based on a 90% SO_2 removal efficiency. All costs are dependent upon the sulfur content of the fuel; the cost variance for FGD systems on new coal fired boilers is shown by the shaded area. The upper and lower limits correspond to 5.0 and 2.0% sulfur respectively[D].



OPERATING COSTS

Operating costs for the Wellman-Lord process are not available for industrial applications. Northern Indiana Public Service has reported the operating cost for their 115 MW application at 8.1 mills/kWhr[3]. Costs were estimated by EPA/TVA using 1978 cost information. These costs are shown below[2]. The costs shown are total operating costs[C] and are based upon a 90% SO_2 removal efficiency. All costs are dependent upon the sulfur content of the fuel; the cost variance for FGD systems on new coal fired boilers is shown by the shaded area. The upper and lower limits correspond to 5.0 and 2.0% sulfur respectively. Costs include the production of elemental sulfur.



OPERATING EFFICIENCIES

The operating efficiencies for the Wellman-Lord process, similar to the aqueous sodium process (1.4.1.4) are very high compared to the lime or limestone processes (1.4.1.1, 1.4.1.2). Systems can be designed for removal efficiencies in excess of 95% because the sodium alkali scrubbing agent is very reactive. Availability of the Wellman-Lord process has been reported to be greater than 97-98% in most installations. This availability data is for the absorption area only in sulfuric acid plants, Claus plants, and oil fired boilers.

ENVIRONMENTAL PROBLEMS

The Wellman-Lord process may create environmental problems in the following areas.

1) Sodium sulfate generated from the process may require disposal if a market is not available. Although the quantity is relatively small compared to the throwaway process, the material is soluble in water and may lead to water pollution problems.
2) Stack emissions may create an "acid rain" under certain weather conditions if reheat is not provided.

NOTES

A) A double effect evaporator can be used to significantly reduce the operating costs (up to 45% reduction in steam requirements).

B) Soda ash can be used for makeup as well. The reaction would then be:

$$Na_2CO_3 + 2NaHSO_3 \longrightarrow 2Na_2SO_3 + H_2O + CO_2$$

C) The cost data include amortized capital investments, overhead, utilities, raw materials, labor and maintenance; but do not include by-product credits.

D) These costs also include an Allied Chemical sulfur plant.

MANUFACTURER / SUPPLIER

Davy Powergas Inc.

REFERENCES

1) Federal Power Commission, "The Status of the Flue Gas Desulfurization Applications in the United States: A Technological Assessment", A staff report of the Burea of Power, (July 1977).
2) "Proceedings: Symposium on Flue Gas Desulfurization; New Orleans, March 1976, Volume 1", EPA 600/2-76-136a, (May 1976).
3) Pedco Environmental, "Summary Report Utility Flue Gas Desulfurization Systems - Oct. and Nov. 1977", Prepared for U.S. Environmental Protection Agency, Contract 68-01-4147.

CLASSIFICATION Gas Treatment	**GENERIC DEVICE OR PROCESS** Liquid Scrubbers/ Contactors (Venturi Scrubbers)
SPECIFIC DEVICE OR PROCESS Dual Throat Variable Venturi	**NUMBER** 1.4.6.5

POLLUTANTS CONTROLLED		**AIR**				**WATER**				**LAND**			
		GASES		**PARTICULATES**		**DISSOLVED**		**SUSPENDED**		**LEACHABLE**		**FUGITIVE**	
x	**ORGANIC**			x									
x	**INORGANIC**	x	SO_2	x									
	THERMAL												
	NOISE												

PROCESS DESCRIPTION

Figure 1 shows a schematic diagram of the dual throat variable venturi scrubber. Contaminated gas enters through a rectangular duct and passes over a flow dividing insert. This insert can be moved up or down to infinitely vary the distance between the scrubber walls and the insert. The gas stream is contacted with water by two spray pipes located directly over each of the two rectangular venturi throats formed by the insert. Turbulent mixing of the gas and liquid streams occurs in each throat. This mixing wets the particulate matter and provides excellent mass transfer. Odor problems can be eliminated and non-condensable gases such as SO_2, HCl, HCN and H_2S can be absorbed simultaneously with particulate removal. The degree of mixing and consequently the scrubbing efficiency can be varied depending upon the location of the insert. A higher insert position, reduces the throat size, increases the turbulence and the efficiency, but it also decreases the capacity for a given pressure drop. The dual throat design combines long, constant cross sectional area throats with a small fixed angle of expansion to provide for maximum turbulent mixing and maximum pressure recovery. This minimizes frictional losses.

Gas from the venturi section expands in a flooded elbow where most of the water is removed. Any entrained water is removed in a cyclonic separator which may be equipped with a fiber mat mist eliminator if necessary.

Certain applications may require the addition of oxidation or neutralization chemicals to the scrubber water. Hydrogen peroxide, lime, soda ash are used in this manner to react with the absorbed components and increase efficiency. Materials of construction can vary greatly depending upon the application and the scrubber solution. Exotic alloys and a variety of liners can be used for this purpose.

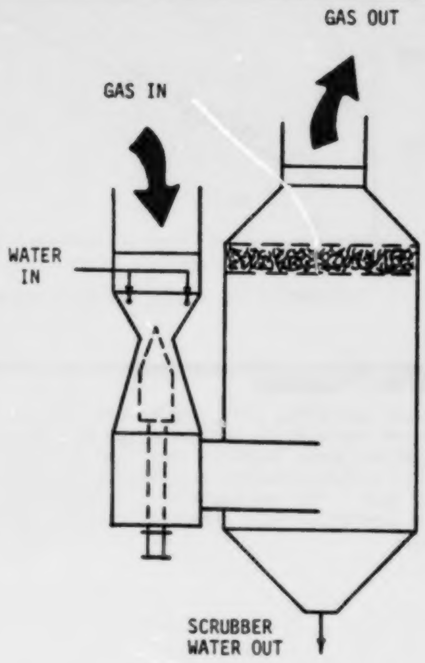


FIGURE 1. DUAL THROAT VENTURI

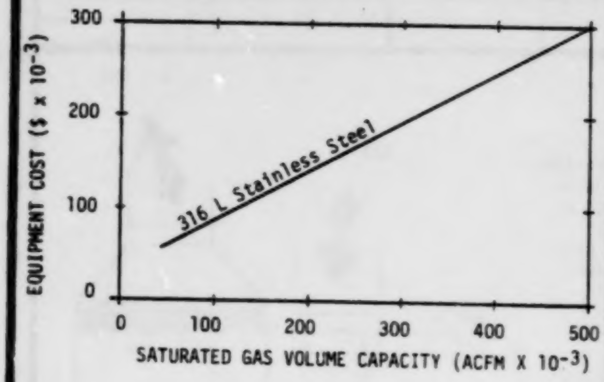
APPLICATION RANGE

The dual throat variable venturi can handle gas streams with particles ranging in size from 0.5 to 100 microns, but it is best suited to a size range from 1 to 40 microns. The particulate loading can range from 0.08 to 2.0 grains/SCF. Soluble gases such as SO_2, HCl, HCN and H_2S can be effectively absorbed in this unit as well. The unit is manufactured in standard sizes from 50,000 to 500,000 ACFM saturated capacity. The dual throat variable venturi has been used in conjunction with the Double Alkali System (1.4.1.10) and in Sodium Scrubbing without regeneration (1.4.1.32) to remove SO_2, kiln dust and fly ash.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	236 m^3/s	500,000 ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

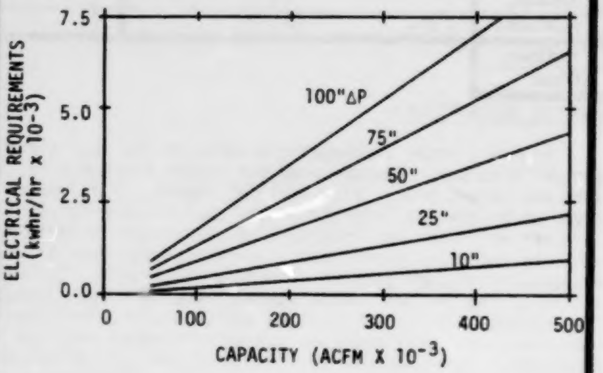
CAPITAL COSTS

The capital costs for the dual throat variable venturi scrubber are shown below[A]. The costs are March, 1978; and are dependent upon size, application and the materials of construction. Contact the manufacturer for detailed cost information.



OPERATING COSTS

Operating costs can vary greatly depending upon the the application. In most cases, the major contributor to the operating cost is the increased load on the fan drive unit. Electrical requirements for various gas flows are shown below for a number of pressure drops[B].



OPERATING EFFICIENCIES

Actual operating efficiencies are highly dependent upon the application and cannot be estimated here. The outlet grain loadings have been reduced to as low as 0.01 grains/SCF, but this cannot be obtained in every case. The manufacturer will guarantee an outlet grain loading of 0.03 grains/SCF for all units of this design.

ENVIRONMENTAL PROBLEMS

Scrubber water is generated in this unit and must be treated to remove suspended solids and any absorbed gases before it can be discharged. Other emissions include fugitive liquid and air emissions. Gaseous and particulate constituents which are not removed from the gas stream may also be a problem.

NOTES

A) Source: Direct communications with FMC Corp.

B) Compression effects were neglected for this estimate. Fan efficiency was assumed to be 67%.

MANUFACTURER / SUPPLIER

FMC Corp.

REFERENCES

1) FMC Corp., "Type TI Dual Throat Variable Scrubber", Bulletin 25100-A.
2) FMC Corp., "Boiler Emissions Control", Bulletin 25300.

CLASSIFICATION Gas Cleaning	**GENERIC DEVICE OR PROCESS** Liquid Scrubbers/Contactors (Venturi Scrubbers)
SPECIFIC DEVICE OR PROCESS Ejector Venturi Scrubber	**NUMBER** 1.4.6.8

POLLUTANTS CONTROLLED	**AIR**				**WATER**				**LAND**			
	GASES		**PARTICULATES**		**DISSOLVED**		**SUSPENDED**		**LEACHABLE**		**FUGITIVE**	
x **ORGANIC**			x	> 1 Micron								
x **INORGANIC**	x	Soluble Gases	x	> 1 Micron								
THERMAL												
NOISE												

PROCESS DESCRIPTION

Figure 1 shows a schematic diagram of a typical ejector-type venturi scrubber. In this design, a high velocity liquid spray creates a draft which draws contaminated gas into the throat. The venturi effect provides for maximum entrainment of particulate by the scrubbing liquid and thoroughly mixes both phases. The gas-liquid mixture is discharged from the venturi scrubber over a separating baffle and into a knock-out box. Liquid effluent from this separation step can be discharged after treatment or recycled to the scrubber. Cleaned gas from the separator can be discharged to the atmoshere or sent to a second stage for further purification. Ultra high efficiencies of 99.5% plus can be obtained in this manner.

The nozzle, normally supplied with the scrubber, provides a medium coarse spray, fine enough to provide efficient gas scrubbing and yet coarse enough to allow for easy separation of the entrained liquid. The nozzle is designed to ensure that the spray angle and characteristics are correct for each size scrubber. Other considerations taken into account for the nozzle design are the desired scrubbing efficiency and the air handling requirements. The nozzle can be manufactured in stainless steel, special plastics, cast iron, or butyl rubber. It can be made in other special materials if the application warrents it. The scrubber itself can be made from any workable material such as special alloys, plastics including PVC, fiberglass reinforced plastic and Haveg. In addition, the scrubber can also be lined with a variety of corrosion resistant materials.

Some ejector venturi scrubbers are available for mounting on an existing tank, thus eliminating the need for the separator. In addition, the separator can be over-sized to allow for liquid storage prior to discharge or recycle. A strainer is provided for most recycle applications to eliminate nozzle plugging.

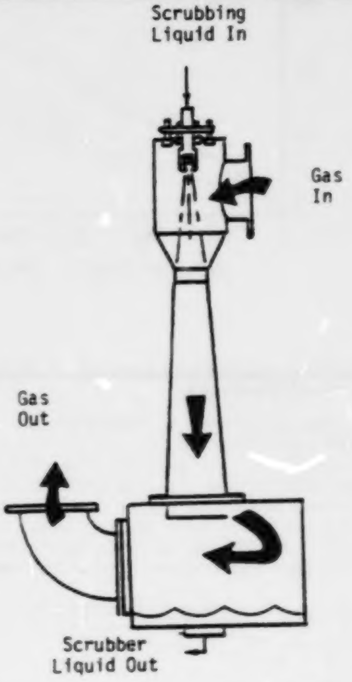


Figure 1. EJECTOR VENTURI SCRUBBER

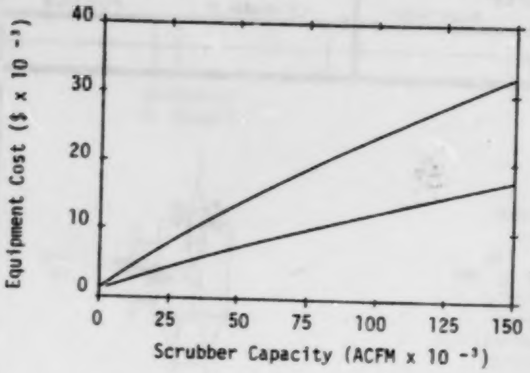
APPLICATION RANGE

The ejector venturi is designed for scrubbing large volume gases, vapors, fumes and dusts. The system is available in sizes from 1 1/2" to 96", and can produce gas flows up to 173,000 ACFM and higher. Typical ejector type venturi scrubbers can be designed to handle large amounts of condensables, to cool large volumes of hot non-condensables, and to absorb gases such as Cl_2, HCI, SO_2 and NH_3.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	81.6 m³/s	173,000 ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

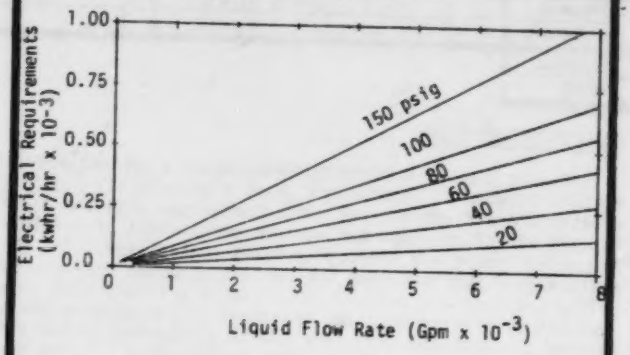
CAPITAL COSTS

Capital costs for ejector-type venturi scrubbers are shown below. These costs are March 1978, costs and were estimated from manufacturer's data. Prices are for the scrubber only with no separator or auxillaries.



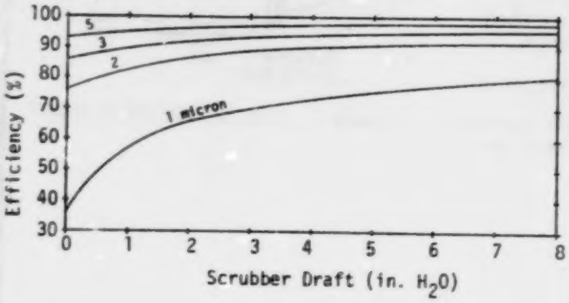
OPERATING COSTS

Since there are no moving parts in the ejector venturi scrubber, maintenance costs are very low. The major electrical requirement is that needed to supply liquid to the spray nozzle. Electrical requirements are shown below for various flow rates at several nozzle back pressures[B]. In general, liquid will be required at a rate of 25 to 86 gpm/1000 CFM.



OPERATING EFFICIENCIES

The efficiency is dependent upon the pressure of the scrubbing liquid, and on the dust loading of the inlet gas. In general, the efficiency is not acceptable for particulate under 1 micron in size. Efficiencies for particles for a variety of scrubber drafts and particle sizes are shown below. Efficiencies for gas absorption is greatly dependent upon the application and are not considered here.



ENVIRONMENTAL PROBLEMS

Scrubber water is generated in this unit and must be treated to remove suspended solids and absorbed gases before it can be discharged. Other emissions include fugitive liquid and air emissions. Gaseous and particulate constituents which are not removed from the gas stream may also be a problem.

NOTES

A) The wide band of costs per ACFM is created from the flexibility of each specific size to handle a wide range of gas flows. The flow of gas through an ejector venturi can be varied by altering the liquid flow rate, the inlet pressure or the outlet pressure.

B) Electrical requirements were estimated for a centrifugal pump with a pump efficiency of 50%.

C) Larger sizes are available on special request.

MANUFACTURER / SUPPLIER

Ametek, Inc., Process Systems Division
Brighton Corp.
Croll-Reynolds Co., Inc.
Graham Manufacturing Co., Inc.
Heil Process Equipment Co., Division of Dart Industries
Jet-Vac Corp., The

REFERENCES

1) Liptak, B.G. ed., Environmental Engineers Handbook, Volume II Air Pollution, Chilton Book Co., Radnor, PA, (1974).

2) Ametek Process Systems, "Pollution Control, Product Recovery, Chemical Recovery," Catalog 7R.

CLASSIFICATION Gas Cleaning	**GENERIC DEVICE OR PROCESS** Liquid Scrubbers/Contactors (Venturi Scrubbers)
SPECIFIC DEVICE OR PROCESS Kinpactor Venturi Scrubber	**NUMBER** 1.4.6.12

POLLUTANTS CONTROLLED		AIR: GASES		AIR: PARTICULATES		WATER: DISSOLVED		WATER: SUSPENDED		LAND: LEACHABLE		LAND: FUGITIVE
x	ORGANIC	☐		x		☐		☐		☐		
x	INORGANIC	☐		x		☐		☐		☐		
☐	THERMAL											
☐	NOISE											

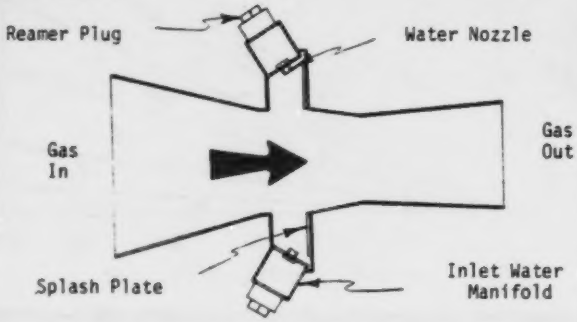


Figure 1. KINPACTOR VENTURI THROAT

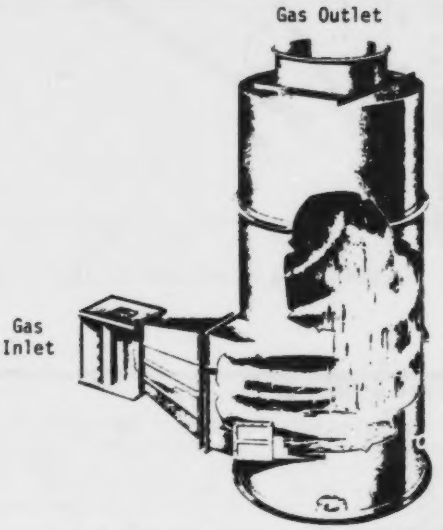


Figure 2. KINPACTOR GENERAL ARRANGEMENT

PROCESS DESCRIPTION

The Kinpactor^A venturi scrubber is a high energy venturi with a specially designed throat, (Figure 1). This design provides the most efficient conversion of potential energy into kinetic energy (velocity) and then allows maximum pressure recovery. The highest possible collection efficiency can be obtained for a given power consumption. Throat velocities of 9,000 to 24,000 ft per minute can be reached.

Water is introduced ahead of the throat by impinging it off of a splash plate. This forms a continuous sheet through which the gas must pass. The nozzles are angled to give the high pressure water the right trajectory and results in complete coverage of the throat area. Manual high pressure water reamers (not shown) are normally included to clean any plugged nozzles. Automatic models are also available. The use of reamers allows the recirculation of scrubber water to the throat, a practice which could otherwise cause plugging problems. The recirculation system must, however, contain some means of clarification or a means to limit the build up of suspended solids.

Water atomized in the throat and the gas move horizontally through a long diverging section and pass into a cyclonic separator (see Figure 2). Clean gas free of any entrained water is discharged from the separator. Scrubber water and the absorbed containants are continuously drained from the bottom of the separator.

The Kinpactor is available in a variable throat model if the application warrents it. Similar to other scrubbers, the Kinpactor can be constructed from a variety of materials to meet specific corrosion resistance requirements.

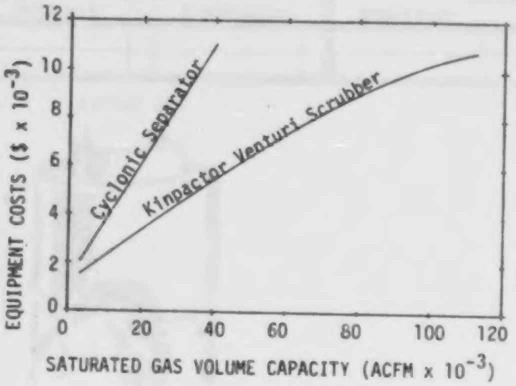
APPLICATION RANGE

The Kinpactor venturi scrubber can be used to remove dust ranging in size down to a sub-micron level. Economics, however, may prohibit the application of this scrubber on particulate over 2 microns in size. The Kinpactor has been successfully used to remove dust from utility flue gas, BOF plant effluents, blast furnace gas, cupalco offgas, and asphalt dryer offgas.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	57 m^3/s	120,000 ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

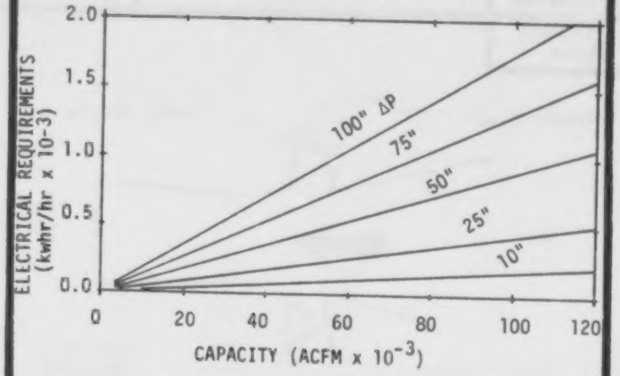
CAPITAL COSTS

Capital cost very greatly depending upon the application. Equipment costs for the Kinpactor scrubber and the cyclonic separator are shown below^B. Costs are March, 1978 and are based upon manufacturer's data.



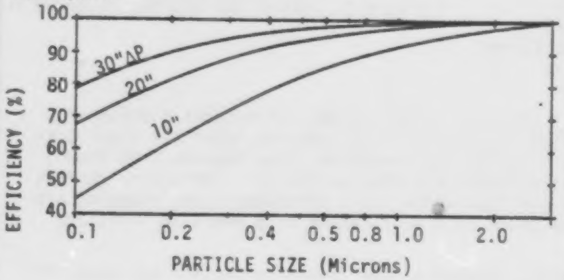
OPERATING COSTS

Operating costs vary greatly depending upon the application. In most cases, the major contributor to the operating cost is the increased load on the fan drive unit. Electrical requirements for various gas flows are shown below for a number of pressure drops^C. The Kinpactor is usually designed to use 8 gal/1000 SCF of water at the throat. This may be recycled, however, and doesn't effect the operating cost a great deal.



OPERATING EFFICIENCIES

Operating efficiencies for the Kinpactor are shown below. This graph relates the collection efficiency to the particle size for a number of different pressure drops. The Kinpactor provides the highest possible collection efficiency for a given power consumption.



ENVIRONMENTAL PROBLEMS

Scrubber water is generated in this unit and must be treated to remove suspended solids and any absorbed gases before it can be discharged. Other emissions include fugitive liquid and air emissions. Gaseous and particulate constituents which are not removed from the gas stream may also be a problem.

NOTES

A) Kinpactor is a trade name of Americal Air Filter.

B) The cost estimate is based upon the following: ΔP = 20" H_2O; saturated gas density factor = 1.0; and 1/4" mild steel construction. The Kinpactor costs include a manual reamer.

C) Compression effects were neglected for this estimate. Fan efficiency was assumed to be 67%.

MANUFACTURER / SUPPLIER

American Air Filter Company, Inc.

REFERENCES

1) American Air Filter Co., "Kinpactor Venturi-Type Wet Dust Collector", Bulletin DC-1-249D-Apr.-01.
2) American Air Filter Co., "AAF Wet Dust and Fume Collectors", Bulletin DC-1-304A-June-01.

CLASSIFICATION Gas Treatment	**GENERIC DEVICE OR PROCESS** Liquid Scrubbers/Contactors (Venturi Scrubbers)	
SPECIFIC DEVICE OR PROCESS Ventri-Rod Scrubber		**NUMBER** 1.4.6.16

	POLLUTANTS CONTROLLED	AIR GASES		AIR PARTICULATES		WATER DISSOLVED		WATER SUSPENDED		LAND LEACHABLE		LAND FUGITIVE	
x	ORGANIC			x									
x	INORGANIC	x	SO_2	x									
	THERMAL												
	NOISE												

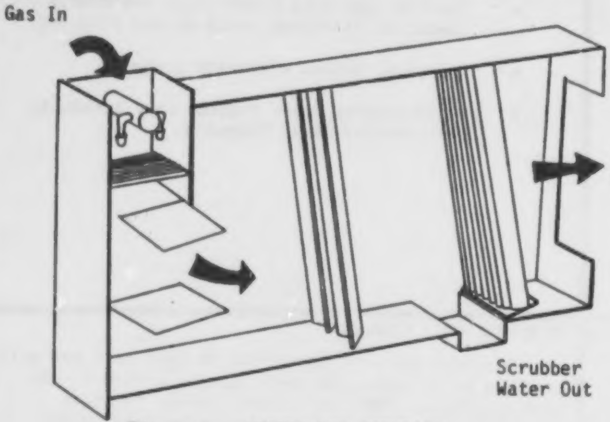


Figure 1. VENTRI-ROD SCRUBBER

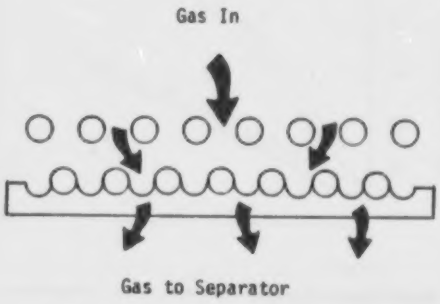


Figure 2. VARIABLE ROD CONFIGURATION

PROCESS DESCRIPTION

The Ventri-Rod Scrubber[A] is shown in Figure 1. Particulate laden gas is contacted with scrubber water as it enters the scrubber. Both scrubber water spray and the dirty inlet gas are directed toward a deck of parallel metal pipes spaced slightly further apart than their diameter to produce a series of short throat venturi openings. This Ventri-rod deck shown in Figure 1 operating in the down-flow position, can also be used effectively in an up-flow or a cross-flow position. Wear resistant, non-clogging ceramic nozzles are used to ensure an even distribution of water over the deck. As the gas passes through the venturi throats, the particulate matter is scrubbed by the entrained water. Scrubber water is removed from the gas stream by two baffle plates and a series of two chevron type mist eliminators. Approximately 90% of the free water is removed by the deceleration of the gas as it passes over the baffle plates. The remaining free water is removed by the mist eliminators.

The Ventri-Rod deck can also be used in conjunction with other types of mist eliminators (Section 1.1.2) or as a conversion kit to upgrade inefficient or obsolete scrubbing equipment. Another configuration which is available for retrofit and as a complete scrubber package is the variable Ventri-Rod scrubber. This scrubber operates similar to the unit described above, but two rod decks are provided in the venturi section (See Figure 2). One deck is fixed and the other is movable to allow adjustment of the venturi throat opening. This provides constant efficiency over a wide range of operating conditions without any major changes to the rod size or position.

The Ventri-Rod scrubber can be fabricated from a wide variety of materials, from mild steel to high cost alloys. Coated materials can also be used.

APPLICATION RANGE

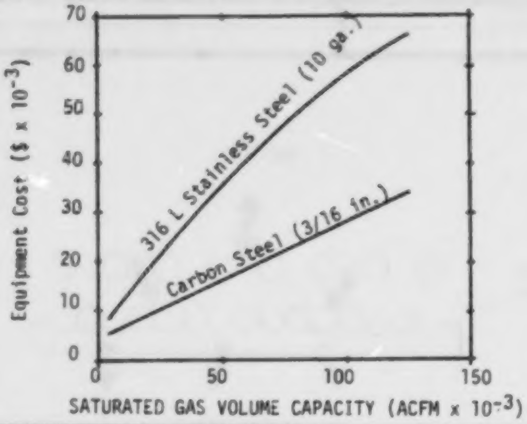
The Ventri-Rod scrubber functions very well at low pressures. Inlet loadings in excess of 20 grains can be handled. Liquid to gas ratios can range from 2 to 15 gal per 1000 CFM. Installations to date have ranged in capacity from 1000 to 600,000 ACFM, and have handled everything from iron oxides dust to fly ash.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	.5 to 37.3 KPa	0.7 to 5.4 psi
VOLUMETRIC RATE	283 m^3/s	600,000 ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

The FOB costs for standard sizes of Ventri-Rod package scrubbers are shown below[B].

These costs may fluctuate depending upon the configuration. Costs are March, 1978 and are based upon manufacturer's data.



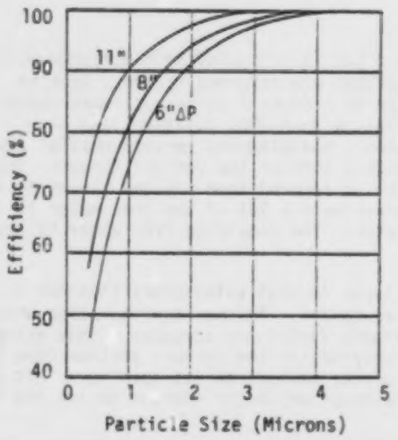
OPERATING COSTS

Operating cost information is not available. Design features which may effect the operating costs are listed below:

- Ceramic spray nozzles resist wear and clogging.
- Venturi rods are free to rotate and vibrate. This minimizes build-up and evenly distributes wear.
- Chevron type mist eliminators are widely spaced to eliminate build-up and plugging.
- Oversized drains eliminate plugging.
- Quick opening doors provide easy access to maintain scrubber internals.

OPERATING EFFICIENCIES

The rod size and position can be varied to improve operating efficiencies but this usually decreases the capacity. General operating efficiencies shown below[C].



ENVIRONMENTAL PROBLEMS

Scrubber water is generated in this unit and must be treated to remove suspended solids before it can be discharged. Other emissions include fugitive liquid and air emissions. Gaseous and particulate constituents which are not removed from the gas stream may also be a problem.

NOTES

A) Ventri-Rod scrubber is a registered trademark of Environeering, Inc.

B) Larger sizes may be shipped in sections and welded together in the field.

C) Operating efficiencies are general in nature and should not be used for design purposes. Source: Environeering, Inc.

MANUFACTURER / SUPPLIER

Environeering, Inc., Subsidiary of Riley Stoker Corp.

REFERENCES

1) Environeering, Inc., "A-33 Ventri-Rod Scrubber", Bulletin 110-10/75.

CLASSIFICATION
Gas Cleaning

GENERIC DEVICE OR PROCESS
Liquid Scrubbers/Contactors (Venturi Scrubbers)

SPECIFIC DEVICE OR PROCESS
Ametek High Energy Venturi Scrubber

NUMBER
1.4.6.23

POLLUTANTS CONTROLLED		AIR GASES	AIR PARTICULATES	WATER DISSOLVED	WATER SUSPENDED	LAND LEACHABLE	LAND FUGITIVE
x	ORGANIC		X				
x	INORGANIC	X	X				
	THERMAL						
	NOISE						

PROCESS DESCRIPTION

The Ametek high energy venturi scrubber, shown in Figure 1, utilizes a high pressure drop to achieve 99%+ removal efficiency. The gas enters the throat area (detailed at right), and is accelerated to increasingly higher velocities as the cross sectional area decreases. Scrubbing liquid is introduced at two points, tangentially to a trough above the gas inlet creating a cylindrical liquid wall around the incoming gas and through a spray nozzle at the point of maximum turbulence in the throat. This design eliminates the "wet-dry zone" solids build up, and maximizes the relative velocities between the gas and liquid streams which atomizes the motive liquid droplets. As the gas decelerates through the tapered venturi tail, further impaction and agglomeration of the droplets and contaminants occurs. The gas-liquid mixture passes into a cyclonic separator where any entrained water is removed. Clean gas flows out the top, and contaminated liquor is recycled to the venturi throat. Make-up liquor is added to reduce suspended solids or to limit the concentration build-up of any absorbed contaminants. As make-up is added, concentrated liquor overflows from the separator.

Depending upon the application, the high energy scrubber can be supplied in a variable capacity model, in a number of materials of construction, or with additional equipment, such as a precooler.

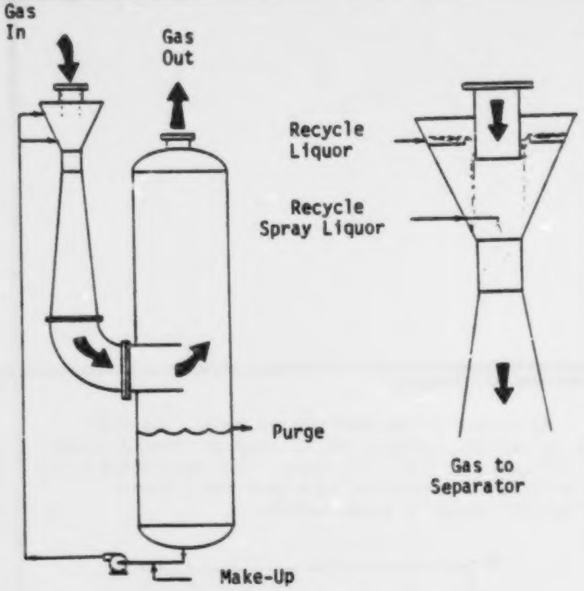


Figure 1. AMETEK HIGH ENERGY VENTURI

APPLICATION RANGE

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	17.5 m^3/s	37,000 ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

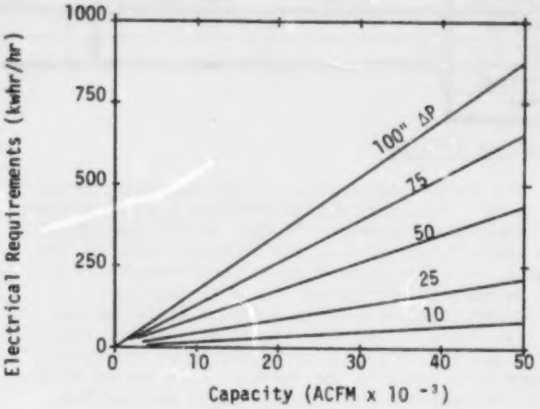
The Ametek high energy venturi scrubber is offered in standard sizes from 1600 to 37,000 cfm and is available in larger sizes on a custom basis.

This scrubber is versatile enough to meet practically every submicron requirement from industrial and commercial effluents gases. It has been used to treat: acid mists; fertilizer plant effluents; iron, coke and silica dust; lime and limestone dust; catalyst dusts; oil fumes; and boiler fly ash, all at 95% or greater efficiency.

CAPITAL COSTS

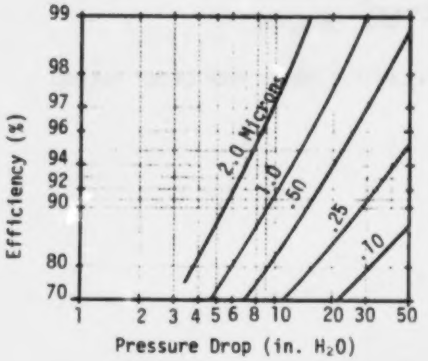
OPERATING COSTS

Operating costs can vary greatly depending upon the application. In most cases, the major contributor to the operating cost is the increased load on the fan drive unit. Electrical requirements for various gas flows are shown below for a number of pressure drops[B].



OPERATING EFFICIENCIES

As stated in the Application Range, the high energy venturi scrubber can be used to treat a number of effluents at high efficiency. The relationship of efficiency versus pressure drop for a number of partial sizes is shown below[C].



ENVIRONMENTAL PROBLEMS

Scrubber water is generated in this unit and must be treated to remove suspended solids and any absorbed gases before it can be discharged. Other emissions include fugitive liquid and air emissions. Gaseous and particulate constituents which are not removed from the gas stream may also be a problem.

NOTES

B) Compression effects were neglected for this estimate. Fan efficiency was assumed to be 67%.

C) This information is typical of the results which can be achieved. Accurate efficiency data can be obtained from the manufacturer.

MANUFACTURER / SUPPLIER

Ametek Inc., Process Systems Division

REFERENCES

1) Ametek Process Systems, "Pollution Control, Product Recovery, Chemical Recovery," Catalog 7R.

CLASSIFICATION Gas Treatment	**GENERIC DEVICE OR PROCESS** Liquid Scrubbers/Contactors (Venturi Scrubbers)
SPECIFIC DEVICE OR PROCESS Multistage Venturi Spray Chamber	**NUMBER** 1.4.6.27

POLLUTANTS CONTROLLED	**AIR** GASES	**AIR** PARTICULATES	**WATER** DISSOLVED	**WATER** SUSPENDED	**LAND** LEACHABLE	**LAND** FUGITIVE
☒ **ORGANIC**	☐	☒ > 1 Micron	☐	☐	☐	☐
☒ **INORGANIC**	☒ Soluble Gases	☒ > 1 Micron	☐	☐	☐	☐
☐ **THERMAL**						
☐ **NOISE**						

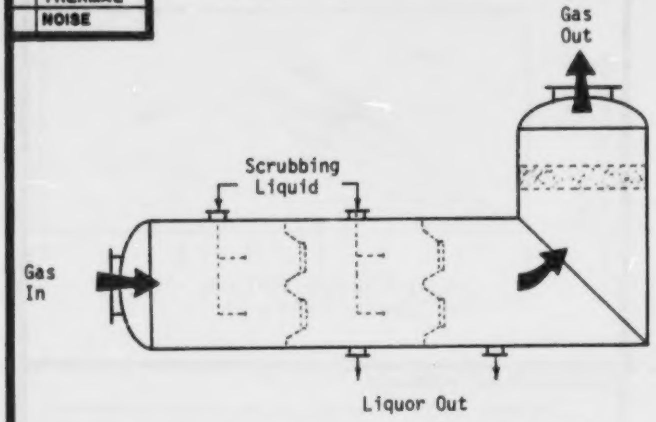


Figure 1. MULTISTAGE VENTURI SPRAY CHAMBER

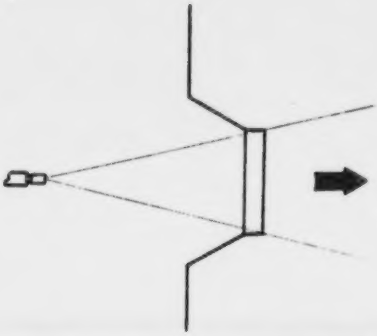


Figure 2. VENTURI THROAT

PROCESS DESCRIPTION

The multistage venturi spray chamber (Figure 1) is a horizontal liquid contacting device utilizing the turbulence caused by the venturi stages to affect particulate and gaseous pollutant removal. Gas enters the chamber and is contacted with scrubbing liquor as it passes through the first set of venturi throats, detailed in Figure 2. The atomizing spray efficiently wets any particulate matter and absorbs contaminants present in the gaseous phase. Much of the liquor from the first stage is settled out and the gas moves on to the second stage where the final clean-up is accomplished. Prior to discharge, the gas is passed through a mist eliminator to remove any entrained water.

Currently, this scrubber is manufactured in two general configurations, one for particulate laden effluents and one for effluents containing only gaseous pollutants. The configuration for gaseous pollutants, shown in Figure 1, has a 90° turn before the gas passes through a high efficiency mist eliminator. The scrubber for particulates is similar to this except that the elbow is eliminated and a widely spaced chevron separator is used to remove the entrained water. This modification greatly reduces the possibility of plugging in the separation section.

Each multistage venturi spray chamber is designed to the specific application. The venturi throat is available in five standard sizes and each scrubber size has a standard number and arrangement. Additional contact time or additional mass transfer can also be designed into the system by adding a blank stage or an additional venturi stage respectively. Each stage adds approximately four feet to the scrubber length.

Scrubbing liquor can be supplied in a number of arrangements utilizing once through flow or recirculation. The inlet piping for all stages can be connected to the same header to provide cross flow contacting or each stage can be piped separately, utilizing the discharge liquor from the other stages to facilitate cocurrent or countercurrent contacting. If the scrubbing water is supplied at a sufficient pressure and flow rate, this scrubber can produce a slight draft, similar to the ejector-type venturi (1.4.6.8). The multistage venturi spray chamber, like most scrubbers can be supplied in a variety of materials to meet most corrosion resistance requirements.

APPLICATION RANGE

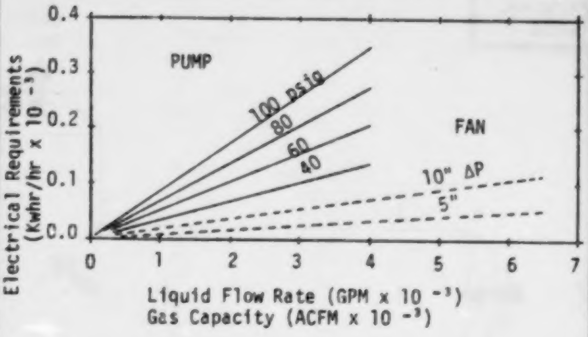
The multistage venturi spray chamber can be used to efficiently remove soluble gases, particulate and mists from gaseous effluents. It can also be used to condense or cool the incoming gas. This scrubber, however, is not recommended for an application involving mists having a particle size less than 1 micron. The multi-stage venturi spray chamber is available in standard sizes from 4000 to 65,000 cfm.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	30.7 m³/s	65,000 ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

The two major contributors to the operating costs are the fan requirements for the increased load due to the scrubber and the pumping costs for the scrubber spray system. Electrical requirements for both of these factors are shown below[A]. Pumping costs are shown in solid lines for a number of nozzle pressures. Fan costs are shown in dotted lines for two scrubber back pressures[B].



OPERATING EFFICIENCIES

The multistage venturi spray chamber can be designed for almost any desired efficiency of soluble gas removal. This can be done by varying the number of stages, the liquid rate, the liquid pressure, or the mode of liquid addition or recycle.

ENVIRONMENTAL PROBLEMS

Scrubber water is generated in this unit and must be treated to remove suspended solids and any absorbed gases before it can be discharged. Other emissions include fugitive liquid and air emissions. Gaseous and particulate constituants which are not removed from the gas stream may also be a problem.

NOTES

A) Gas compression effects were neglected for this estimate. Static efficiency for the fan estimated to be 67%, and the pump efficiency was assumed to be 50%. Liquid requirements can range from 5 to 50 gpm per 1000 cfm.

B) Higher liquid pressures tend to reduce the scrubber back pressure. For the smallest venturi throats, the maximum ΔP encountered would be 10" H_2O. Pump requirements are found using a liquid flow rate and a nozzle back pressure (psig). Fan requirements are found using the gas capacity and a scrubber back pressure (in H_2O).

MANUFACTURER / SUPPLIER

Ametek Inc., Process Systems Division

REFERENCES

1) Ametek Process Systems, "Pollution Control, Product Recovery, Chemical Recovery," Catalog 7R.

CLASSIFICATION Gas Treatment	**GENERIC DEVICE OR PROCESS** Liquid Scrubbers/Contactors (Venturi Scrubbers)
SPECIFIC DEVICE OR PROCESS Ventri-Sorber	**NUMBER** 1.4.6.33

POLLUTANTS CONTROLLED		**AIR**				**WATER**				**LAND**			
			GASES		**PARTICULATES**		**DISSOLVED**		**SUSPENDED**		**LEACHABLE**		**FUGITIVE**
	ORGANIC												
x	**INORGANIC**	x	SO_2										
	THERMAL												
	NOISE												

PROCESS DESCRIPTION

The Ventri-Sorber[A] is a countercurrent, multiple stage venturi scrubber, with a design very similar to the Ventri-Rod Scrubber (1.4.6.16). Figure 1 shows a Ventri-Sorber with six Ventri-Rod Decks. Gas enters at the bottom and is contacted with scrubber solution as it moves upward through the decks of parallel metal pipes. Turbulent mixing is created at each stage by the venturi action of the deck, and provides maximum mass transfer. Liquid is introduced above the decks by open pipes to prevent plugging.

Cleaned gas passes through a two-stage Chevron type mist eliminator to remove any entrained water. The blades of the mist eliminators are continuously washed to clean the surface and to assure maximum moisture removal. Clean water should be used in the eliminator recycle system to reduce solids accumulation and to ensure superior performance.

The rods, are free to rotate slightly. This prevents scaling, buildup and evenly distributes wear. The spacing of the rods can be adjusted to achieve uniform gas velocity through out the scrubber without altering the overall pressure drop.

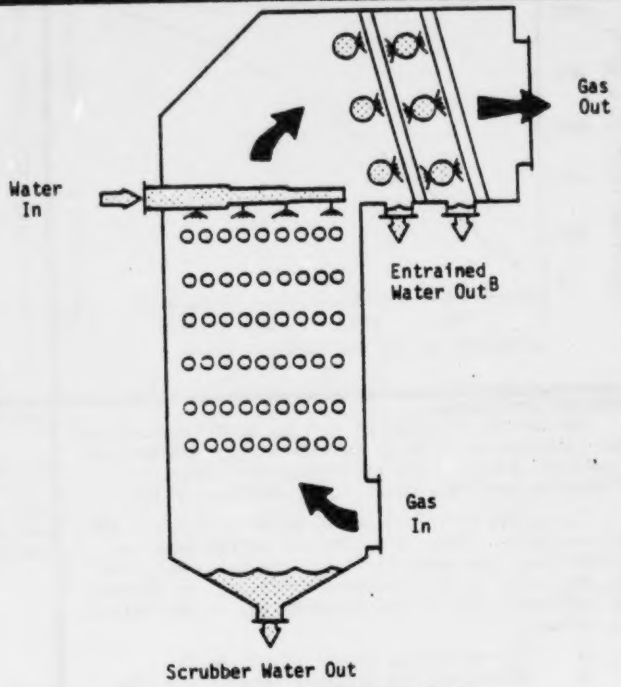


Figure 1. VENTURI SORBER

The variable Ventri-Rod configuration (see Device 1.4.6.16) can be incorporated in this scrubber. The adjustable throat size allows efficient operation during boiler turndown or because of any other reduction in the load. Normally, one of the rod decks is replaced with this feature and the remaining stages are left unaltered.

The Venturi-Sorber is designed mainly for absorportion but a separate particulate stage can be incorporated. This stage would be identical to the Ventri-Rod deck described in 1.4.6.16. Similar to other scrubbers, the Venturi-Sorber can be constructed from a variety of materials to meet specific corrosion resistance requirements.

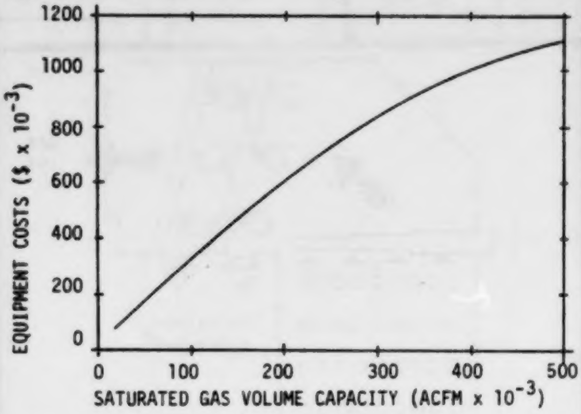
APPLICATION RANGE

The Ventri-Sorber was specifically designed to absorb SO_2 from boiler flue gases with loading up to 4000 ppm SO_2. Absorbers can be supplied in single units up to 600,000 ACFM capacity and is capable of handling flue gas from a 200 MW generating facility. The Venturi-Sorber has been used in applications using limestone, magnesium oxide and lime slurries. It operates efficiently with low pressure drops over a range of liquid-to-gas ratios from 5 to 70 gal/1000 CFM. The absorber itself will handle velocities up to 900 ft/min and the mist eliminator up to 100 ft/min.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	283 m^3/s	600,000 ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

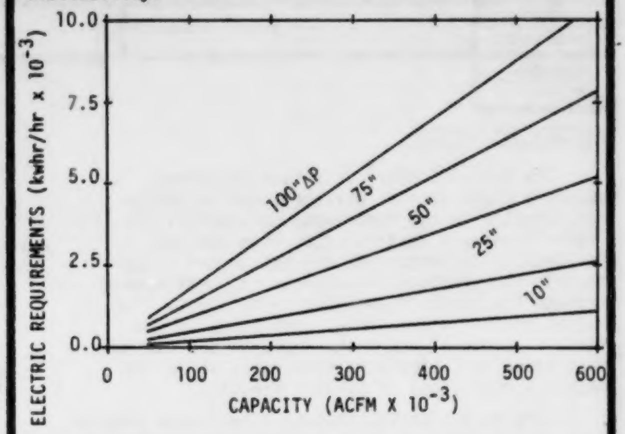
CAPITAL COSTS

The capital costs for the Ventri-Sorber are shown below[C]. The costs are March, 1978, and are for a Flake-glass lined scrubber made of 1/4" mild steel with 316LSS tubes and an FRP mist eliminator. These materials are typical for an SO_2 limestone scrubber.



OPERATING COSTS

The major operating cost is the increased fan load due to the scrubber. Power requirements are shown below[D]. The open design of the scrubber greatly reduces the possibility of plugging increasing scrubber availability.



OPERATING EFFICIENCIES

Operating efficiencies for the Ventri-Sorber have been reported as being up to 98% for SO_2 removal with a suitable alkali. The efficiency for the mist eliminator have been shown to be essentially 100%.

Operating efficiencies for other pollutants are not available. These efficiencies depend upon the application, the absorbtivity of the pollutant, and the chemicals in the scrubbing solution. In general the efficiency can be increased by any of the following methods.

- Increasing the number of rod decks
- Decreasing the distance between the rods
- Increasing scrubber water rate

All of the above operations will also increase the pressure drop for a given flow rate.

ENVIRONMENTAL PROBLEMS

Scrubber water is generated in this unit and must be treated to remove absorbed gases and any suspended solids before it can be discharged. Other emissions include fugitive liquid and air emissions. Gaseous and particulate constituents which are not removed from the gas stream may also be a problem.

NOTES

A) Ventri-Sorber is a regestered trademark of Environeering, Inc.
B) Entrained water can be recycled to the mist eliminator sprays.
C) Source: Direct communication with Environeering, Inc.; budget prices only.
D) Compression effects were neglected for this estimate. Fan efficiency was assumed to be 67%.

MANUFACTURER / SUPPLIER

Environeering, Inc., Subsidiary of Riley Stoker Corp.

REFERENCES

1) Environeering, Inc., "A-5 Ventri-Sorber Scrubber", Bulletin 114-12/77.

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Liquid Treatment	Settling, Sedimentation (Oil Skimmers)

SPECIFIC DEVICE OR PROCESS	NUMBER
Absorbent Belt Skimmer	2.1.6.1

POLLUTANTS CONTROLLED	AIR GASES	AIR PARTICULATES	WATER DISSOLVED	WATER SUSPENDED	LAND LEACHABLE	LAND FUGITIVE
☒ ORGANIC	☐	☐	☐	☒	☐	☐
☐ INORGANIC	☐	☐	☐	☐	☐	☐
☐ THERMAL						
☐ NOISE						

PROCESS DESCRIPTION

This skimmer consists of a moving belt made from a stranded, open-cell synthetic foam material. Surface oil is attracted by a induction pump which pulls about 50 gpm of fluid through the belt. Oil clings to the strands as water flows through the open cells. Oil and oil-soaked debris are lifted from the surface of the water on a continuous conveyor of the absorbent belt material. Entrained oil is then wrung from the belt by a squeeze roller into an oil sump. Oil-soaked debris is retained on a bar screen above the sump.

Both fixed and floating installations are used.

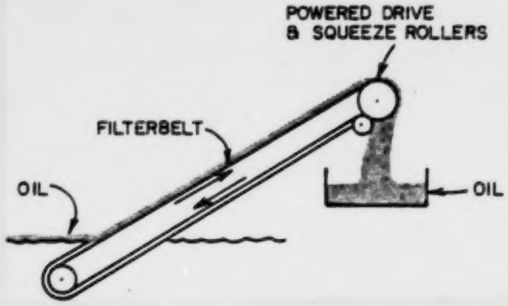


Figure 1. ABSORBENT BELT SKIMMER

APPLICATION RANGE

Designed to eliminate small quantities of oil from relatively large quantities of water. Will tolerate and separate small debris. Very effective with high-viscosity oils which give difficulties with adsorbent surface skimmers.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Approximately $10,000 (1977) depending on materials of construction and design options.

OPERATING COSTS

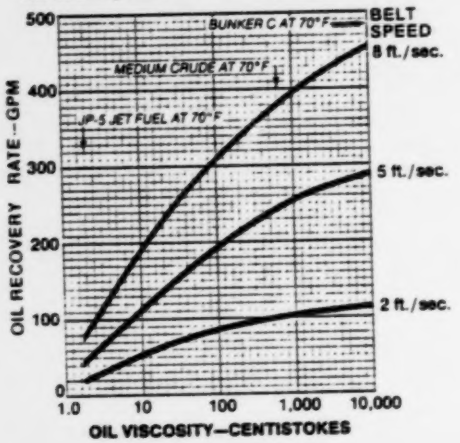
Conveyor drive - 1/2 hp

Induction pump - 1-1/2 hp

Transfer pump - variable

OPERATING EFFICIENCIES

Oil recovery rate for a 3' wide Filterbelt A



ENVIRONMENTAL PROBLEMS

NOTES

A) Industrial model has one-foot wide belt.

MANUFACTURER / SUPPLIER

Marine Construction & Design Co.
Rex Chainbelt, Inc.

REFERENCES

1) Product Bulletin, Marco.

CLASSIFICATION
Liquid Treatment

GENERIC DEVICE OR PROCESS
Settling, Sedimentation (Oil Skimmers)

SPECIFIC DEVICE OR PROCESS
Absorbent Drum Skimmer

NUMBER
2.1.6.2

POLLUTANTS CONTROLLED	AIR		WATER		LAND	
	GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
☒ ORGANIC	☐	☐	☐	☒	☐	☐
☐ INORGANIC	☐	☐	☐	☐	☐	☐
☐ THERMAL						
☐ NOISE						

PROCESS DESCRIPTION

The absorbent drum skimmer uses a synthetic foam material which has a selective affinity for oil in the presence of water. Mounted on a rotating drum, this material absorbs floating oil contaminants. When the foam is mechanically squeezed, oil carrying little more than trace amounts of water is released. Diverted to a sump, the oil can be pumped to a receiving vessel for disposal or recovery.

The foam cartridge is easily replaceable. Both variable and constant speed drives available and both fixed and floating installations are used.

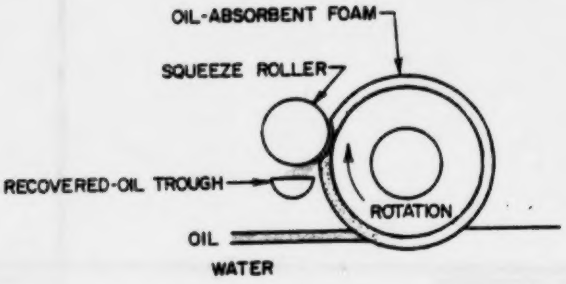


Figure 1. ABSORBENT DRUM SKIMMER

APPLICATION RANGE

Depending on viscosity of oil being recovered, and pore size of foam cartridge being used, maximum recovery rates range from 5 to 50 gpm.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

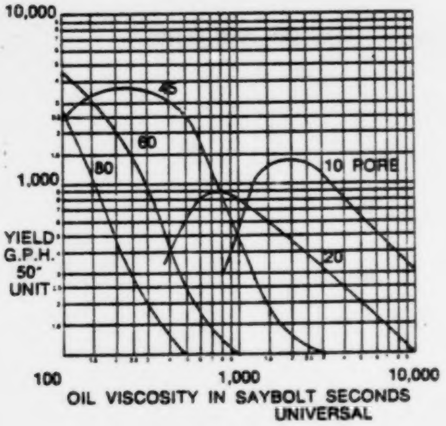
25- inch Drum = $16,500 (1977)

50- inch Drum = $18,500 (1977)

Above costs are for single-speed electric drive. Costs are higher for variable speed and flotation options.

OPERATING COSTS

OPERATING EFFICIENCIES



ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Peabody Welles

REFERENCES

1) Product Bulletin, Peabody Welles

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil Skimmers)
SPECIFIC DEVICE OR PROCESS Adsorbent Rope Skimmer	**NUMBER** 2.1.6.3

	POLLUTANTS CONTROLLED	AIR: **GASES**		AIR: **PARTICULATES**		WATER: **DISSOLVED**		WATER: **SUSPENDED**		LAND: **LEACHABLE**		LAND: **FUGITIVE**
X	**ORGANIC**	☐		☐		☐		X		☐		☐
☐	**INORGANIC**	☐		☐		☐		☐		☐		☐
☐	**THERMAL**											
☐	**NOISE**											

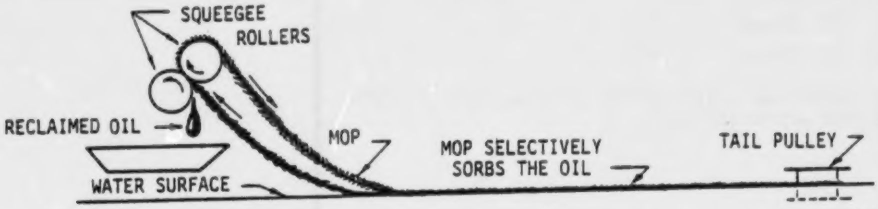


Figure 1. ADSORBENT ROPE OIL SKIMMER(1)

PROCESS DESCRIPTION

The rope is a continuous length of mop made of thin oleophilic plastic fibers woven to a plastic core or base. Both the fibers and the base will sorb oil. The fibers form a thick nap along the entire length of rope. Rope mops are available in sizes from 4 inches to 36 inches in diameter and will float on water. The rope mop is threaded through a set of motor-driven roller-wringers followed by exposure of the mop to the oil polluted water. After absorbing oil from the water, the rope passes to the mop engine, where roller-wringers squeeze the oil from the rope and it drops into containment pans. Exiting from the wringers, the mop returns to the water in a continuous cycle.

The path of the rope over the water surface is controlled by means of one or more tail pulleys. When anchored in multiple strings, rope mops can be used as booms. Also available as hand mops and as self-propelled vessels utilizing a multiple-rope system to recover large open-water oil spills.

APPLICATION RANGE

Motor hp	Max. Rope Length	Nom. Rope Length
40	4000 ft	500-1000
15	2000 ft	300-500
8	2000 ft	300-500

The higher the viscosity of the oil, the greater is the sorbing capacity of the rope. Oil/water emulsions will be absorbed in direct ratio to the oil content.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	-40,210 °F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Motor Size, hp	Capacity bbl/hr	Cost 1977 $
1/2, electric	5	2500
6, diesel	8-10	6750
3/4, electric	10-12	6820
6, diesel	10-12	8975
2, electric	100	21,650
8, diesel	100	21,360
15, diesel	200	
40, diesel	400	

Additional costs include floating tail pulleys, and rope mop at $20-28/ft.

OPERATING COSTS

Operating costs in addition to the cost of running the drive motor, should include occasional cleaning of the rope mop.

OPERATING EFFICIENCIES

Capacity varies with rope diameter, rope length, and rope speed. Increase in any of these parameters requires increase in drive motor power.

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Oil Mop, Inc.

REFERENCES

1) Product Bulletins, Oil Mop Inc.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil Skimmers)
SPECIFIC DEVICE OR PROCESS Adsorbent Belt Skimmer	**NUMBER** 2.1.6.4

POLLUTANTS CONTROLLED	AIR		WATER		LAND	
	GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
☒ ORGANIC	☐	☐	☐	☒	☐	☐
☐ INORGANIC	☐	☐	☐	☐	☐	☐
☐ THERMAL						
☐ NOISE						

PROCESS DESCRIPTION

Oil is preferentially adsorbed on the surface of a moving belt. As the continuous belt passes through the water it attracts and holds oily wastes on both sides, pulling them out of the liquid and up toward the head pulley which drives the belt. There may or may not be a tail pulley at the bottom of the belt. Doctor blades remove the oil from both sides of the belt. The oil then drains into a trough or sump from which it flows or is pumped to storage.

The head pulley can be placed as much as several tens of feet above the water surface without significant loss of capacity. This makes it possible to accommodate greatly varying water levels with a fixed installation and at the same time elevate the oil to a convenient height above the surface.

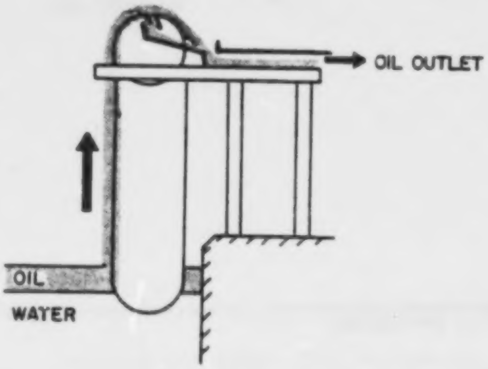


Figure 1. ADSORBENT BELT SKIMMER

Belt skimmers provide an effective means for removing small amounts of oil from large quantities of water. They are capable of sustained performance under continuous operating conditions in lagoons, ponds, sumps, pits, settling tanks, etc. They can be equipped with weather-proof housings and heating devices to permit year-round operation at below freezing temperatures.

Belt materials may be metal, rubber or plastic materials.

APPLICATION RANGE

Capacity varies depending on viscosity of oil, thickness of layer, width and speed of belt. It is also possible to recover solids suspended in the oil layer.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Approximate 1977 cost range.

Belt Width	Removal Rate, gpm	Cost Range
6"	30	$1000
12"	60	$1000-$6000
18"	90	$1000-$10,000
24"	120	$2000-$14,000

OPERATING COSTS

Belt Width	Motor hp
6"	1/4
12"	1/2
18"	1
24"	1

OPERATING EFFICIENCIES

Recovered oil will contain 1 to 5% water. Optimum removal rate is dependent on selecting proper belt speed at operating conditions.

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Aerodyne Development Corp.
Centri-Spary Corp.
Met-Pro Systems, Inc.
Rex Chainbelt, Inc.
Sandvik Conveyor, Inc.
Tenco Hydro, Inc.
Pollution Control Engineering, Inc.
Industrial Metal Fabricators Co.
Monroe Environmental Corp.
Industrial Filter & Pump Manufacturing Co.
Inland Environmental
TRICO Superior, Inc.

REFERENCES

1) Product Bulletin, Sandvik Conveyor, Inc.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil Skimmers)
SPECIFIC DEVICE OR PROCESS Adsorbent Drum Skimmer	**NUMBER** 2.1.6.5

POLLUTANTS CONTROLLED	AIR GASES	AIR PARTICULATES	WATER DISSOLVED	WATER SUSPENDED	LAND LEACHABLE	LAND FUGITIVE
☒ ORGANIC	☐	☐	☐	☒	☐	☐
☐ INORGANIC	☐	☐	☐	☐	☐	☐
☐ THERMAL						
☐ NOISE						

PROCESS DESCRIPTION

Adsorbent drum skimmers depend on the adherence of oils to the surface of a revolving drum, roll, or cylinder. As the drum revolves, oil is lifted from the water surface. The adhering oil film is then removed by a doctor blade, and deposited in a trough or sump to be pumped to storage Capacity depends upon viscosity of the oil, thickness of the oil film on the water surface, the length of the drum and the speed of rotation. It is essentially independent of drum diameter.

Both metal and plastic drum surfaces are used, and both fixed and floating installations. If water levels vary more than a very few inches, a floating installation is necessary.

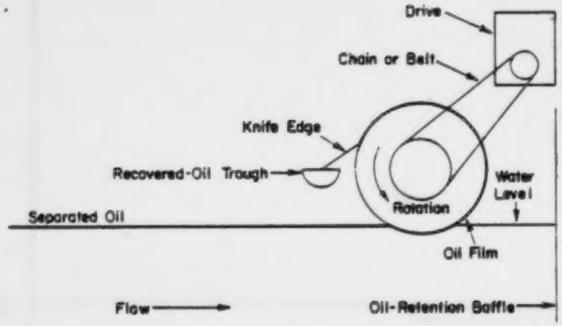


Figure 1. ADSORBENT DRUM SKIMMER(1)

APPLICATION RANGE

Will not pick up large globs of heavy or highly oxidized and non-adherent oils. Maximum recovery rates are on the order of one gpm per foot of length. Cylinders to 18 feet in length available.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Costs vary widely depending on details of installation -- fixed or floating, single or double rolls, single or variable speed drive, type of motor and pump, etc. A rough order of magnitude would be $20,000 (1977) for a 6 to 10 ft drum.

OPERATING COSTS

OPERATING EFFICIENCIES

Free water in recovered oil will be on the order of 5%.

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Surface Separator Systems
Rex Chainbelt
Environmental Equipment Division, FMC Corp.
E & I Corp.

REFERENCES

1) American Petroleum Institute, Disposal of Refinery Wastes Manual, 1969.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil Skimmers)
SPECIFIC DEVICE OR PROCESS Air Jet Skimmer	**NUMBER** 2.1.6.6

POLLUTANTS CONTROLLED	AIR		WATER		LAND	
	GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
☒ ORGANIC	☐	☐	☐	☒	☐	☐
☐ INORGANIC	☐	☐	☐	☐	☐	☐
☐ THERMAL						
☐ NOISE						

PROCESS DESCRIPTION

Air jets may be used in secondary skimming applications or where only a thin film of oil is present. As shown in Figure 1, the jet skimmer is used to push a surface layer of oil and scum across the water surface and into an opening such as a slotted skimming cross pipe located at the influent end. Air skimmer headers may be mounted to a traveling bridge carriage and span the width of the tank. Headers mounted at a narrow impingement angle to the surface, combined with a constant high velocity air jet, drive the scum forward without disturbing surface flow of the tank.

As the jet stream skimming action propels the scum forward toward the slotted pipe skimmer, an adjustable limit switch opens, allowing decanting of the adjacent scum. After the air skimmer crosses this point, the cross skimmer valve closes.

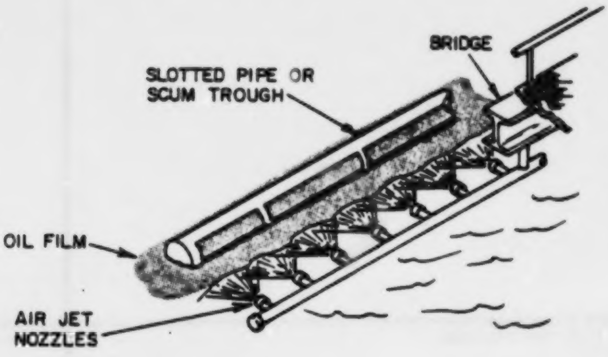


Figure 1. AIR JET SKIMMER(1)

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

OPERATING EFFICIENCIES

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Peabody Welles

REFERENCES

1) Product Bulletin, Peabody Welles

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Liquid Treatment	Settling, Sedimentation (Oil Skimmers)

SPECIFIC DEVICE OR PROCESS	NUMBER
Chain and Flight Skimmer	2.1.6.7

POLLUTANTS CONTROLLED	AIR		WATER		LAND	
	GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
☒ ORGANIC	☐	☐	☐	☒	☐	☐
☐ INORGANIC	☐	☐	☐	☐	☐	☐
☐ THERMAL						
☐ NOISE						

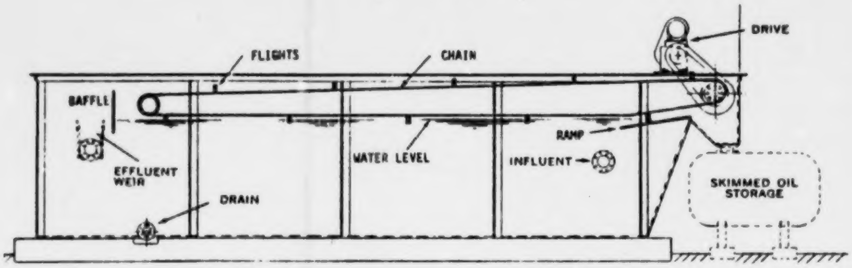


Figure 1. CHAIN & FLIGHT SKIMMER(1)

PROCESS DESCRIPTION

Chain and flight skimmers are designed for the full-width skimming of rectangular tanks. Two parallel drive chains along the sides of the tank are connected by numerous solid flights, or paddles. Generally the ends of the flights have wear shoes which slide on tracks which are attached to the tank walls parallel to the water surface. The full-width flights carry floating material to one end of the tank where it is then scraped up a ramp or beach and into a scum trough.

Flights may be rigidly attached to the chain, or pivoting. End squeegees may be present on some flights to provide positive side scraping. Flights may be made of steel, wood or plastic, and may be partially buoyant to reduce chain load.

Shown in Figure 1 is a 2-shaft independent skimmer, where the lower chain run does the skimming and the upper run returns through the air. For combined skimming and sludge removal, a 4-shaft arrangement can be used, where the bottom chain run scrapes bottom sludge to one end of the tank and the top chain run skims floating contaminants to the opposite end of the tank.

Maximum tank width is on the order of 20-25 feet. For larger systems multiple parallel tanks are necessary. A common chain drive can be used. Tank lengths may be up to 250 feet.

APPLICATION RANGE

Recommended for unusually large quantities of floating grease and scum. Often used in combination scum-sludge removal tanks.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

Resistance to chain wear and elongation is the most important factor influencing operating life and maintenance costs.

OPERATING EFFICIENCIES

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER/SUPPLIER

Envirex Division, Rex Chainbelt
Walker Equipment Division, Chicago Bridge & Iron Co.
Environmental Equipment Division, FMC Corporation
Infilco-Degremont, Inc.
Jeffrey Manufacturing Division, Dresser Industries, Inc.

REFERENCES

1) Product Bulletin, Walker Equipment Division, Chicago Bridge & Iron Co.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil Skimmers)
SPECIFIC DEVICE OR PROCESS Fixed Floating Weir Skimmer	**NUMBER** 2.1.6.8

POLLUTANTS CONTROLLED	**AIR** GASES	**AIR** PARTICULATES	**WATER** DISSOLVED	**WATER** SUSPENDED	**LAND** LEACHABLE	**LAND** FUGITIVE
X **ORGANIC**				X		
INORGANIC						
THERMAL						
NOISE						

PROCESS DESCRIPTION

A fixed floating weir skimmer is a device which is anchored in place but floats on the surface and is capable of rising and falling to follow a changing water level. A constant thickness of water cut can be maintained. It can thus be applied in situations where a slotted pipe skimmer cannot be used because of large fluctuations in water level.

Because oil is less dense than water, a floating skimmer will float higher in water than in oil. This fact can be used to design an automatically operating system. When the skimmer is initially set, the edge of the weir pan is just above the water line and no takeoff occurs regardless of water level. When a sufficiently thick layer of oil has built up the skimmer will sink slightly, due to the lower buoyancy of oil, until oil begins to spill over the weir and flow into the takeoff pipe, as shown in Figure 1. Automatic operation of this type is not recommended with very viscous oils.

Both linear and circular weir geometries may be obtained.

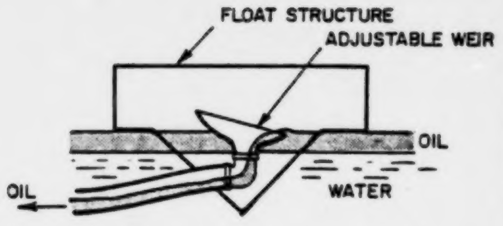


Figure 1. FIXED FLOATING WEIR SKIMMER(1)

APPLICATION RANGE

Used in settling basins, tanks, API separators. Can accept all types of oil. Can be built to handle any oil flow rate.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Prices start at about $1000.

OPERATING COSTS

Operating costs are negligible.

OPERATING EFFICIENCIES

Since only free floating oil is removed, efficiency is not defined.

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Baker Filtration Company
AFL Industries, Inc.

REFERENCES

1) Product Bulletin, AFL Industries, Inc.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil Skimmers)
SPECIFIC DEVICE OR PROCESS Floating Tube Skimmer	**NUMBER** 2.1.6.9

POLLUTANTS CONTROLLED	**AIR** GASES	**AIR** PARTICULATES	**WATER** DISSOLVED	**WATER** SUSPENDED	**LAND** LEACHABLE	**LAND** FUGITIVE
x **ORGANIC**				X		
INORGANIC						
THERMAL						
NOISE						

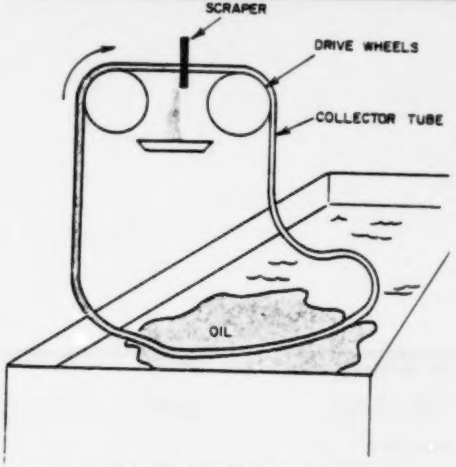


Figure 1. FLOATING TUBE OIL SKIMMER

PROCESS DESCRIPTION

The floating tube oil skimmer removes floating oil from the surface of water and at the same time elevates the oil so that it can flow by gravity into storage tanks. It is used on confined bodies of water such as settling ponds, sumps, coolant reservoirs, steel mill scale pits, ditches and process tanks. A closed loop of flexible, hollow, plastic tubing floats on the water surface. Oil adheres to the surface but water is repelled. The skimmer continuously draws the oil-covered tube through scrapers and returns the clean tube to the water surface to gather more oil. The skimmed oil flows by gravity through the mounting system or a trough to the storage tank. The flexible, floating collector tube is able to snake over and around floating debris to reach the floating oil. It floats up and down with varying liquid levels. The flexible tube flops so that it breaks up crusted oil or grease enabling it to adhere to the tube. Six to 14 feet of tubing floats in the skimming area.

Oil can be lifted up to 60 feet with no loss in capacity. The skimmer can be mounted directly to a tank or on a boom which allows it to be swung out from shore for a pond installation.

APPLICATION RANGE

Light distillates, such as gasoline and kerosene not removed efficiently. Electric de-icing may be required in cold weather.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	0-100 °C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Tank mounted system $1200 and up depending on accessories, such as heaters and decanting tanks. Boom mounted system $3000 and up depending on booms and accessories. 1977 costs.

OPERATING COSTS

Collector tube life 6 months to 4 years. Replacement costs $3/ft. Power required is 1/2 hp electrical motor.

OPERATING EFFICIENCIES

Type of Oil	Capacity, gallons/hr
kerosene	3
diesel oil	3-12
#2 fuel oil	3-12
hydraulic oil	9-30
gear lubricants	45-120
heavy fuel oils	45-120

Capacity increases with viscosity of contaminant being skimmed.

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Oil Skimmers, Inc.

REFERENCES

1) Product Bulletins, Oil Skimmers, Inc.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil Skimmers)
SPECIFIC DEVICE OR PROCESS Free Floating Weir Skimmer	**NUMBER** 2.1.6.10

POLLUTANTS CONTROLLED	AIR		WATER		LAND	
	GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
X ORGANIC				X		
INORGANIC						
THERMAL						
NOISE						

PROCESS DESCRIPTION

Floating weir skimmers are widely used for cleaning up oil spills or small amounts of effluent oil in ponds, lagoons and bays. The most common configuration for floating weir skimmers is a circular weir as shown in Figure 1. Oil or oil plus water flows over a weir into a sump. It is then pumped from the sump to a shore-based separator or storage. Some units, such as that shown, include a pump mounted directly on the skimmer. In other cases, the pump or vacuum tank will be stationed on shore and the suction line will be extended to the skimmer.

Many different techniques are used for adjusting the weir height and thereby adjusting the thickness of surface layer removed by the skimmer. In Figure 1, this is accomplished by adjusting the outboard floats (3); in other cases this adjustment can be accomplished by remote control from the shore or by an automatically compensating mechanism. When the oil thickness is greater than the depth at which the weir is set, 100% oil is skimmed. As the thickness of the oil layer decreases, the ratio of water to oil pumped increases.

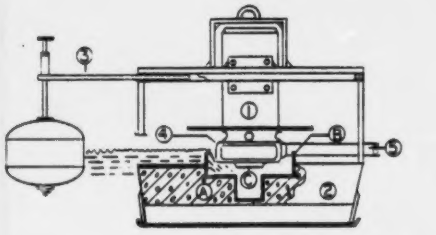


Figure 1. FREE FLOATING CIRCULAR WEIR SKIMMER(1)

LEGEND

1. Motor Drive Unit
2. Flotation Platform
   - A. Flotation Cell
   - B. Skimming Weir
3. Adjustable Float
4. Pump Volute
   - C. Pump Volute Inlet
5. Discharge Pipe

Because they usually are portable and are relatively inexpensive, most floating weir skimmers are used for infrequent spill cleanup jobs which may require moving from one location to another. Some design variations are suitable for permanent installations.

APPLICATION RANGE

Suited to free-floating applications such as ponds and lagoons where only occasional removal is required. Because a large volume of water is normally removed along with any oil layer, a secondary separation step is usually necessary. Not sensitive to properties of oil.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Costs vary considerably from one design to another depending largely on materials of construction and type of pump used. Size is usually limited to that which is easily portable. This will typically mean a pumping capacity of 200 to 400 gpm (water plus oil). Costs begin at about $1600.

OPERATING COSTS

Weir type skimmers may pick up large quantities of water along with any oil. Pumping costs are therefore highly variable, depending upon how accurately the weir depth is controlled to match the existing oil conditions.

OPERATING EFFICIENCIES

Efficiency, in terms of oil recovered per hour of operation, depends on the accuracy of adjustment of the weir height. Because the skimmer is used in free-floating applications, it may require the use of booms or favorable wind conditions to remove completely an oil layer on a pond, lagoon or bay.

ENVIRONMENTAL PROBLEMS

When the oil plus water is pumped from skimmer to shore, passage through the pump may result in an emulsion which is then difficult to break.

NOTES

MANUFACTURER / SUPPLIER

Acme Products Co.
Baker Filtration Co.
Coastal Services, Inc.
Industrial & Municipal Engineering
Megator Corp.
Skim, Inc.
Mapco, Inc.
Seaward International, Inc.
Spill Control Co.
Parkers Systems, Inc.
Kepner Plastics Fabricators, Inc.

REFERENCES

1) Product Bulletin, Skim, Inc.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil Skimmers)
SPECIFIC DEVICE OR PROCESS Radial Arm Skimmers	**NUMBER** 2.1.6.11

POLLUTANTS CONTROLLED	**AIR** GASES	**AIR** PARTICULATES	**WATER** DISSOLVED	**WATER** SUSPENDED	**LAND** LEACHABLE	**LAND** FUGITIVE
☒ ORGANIC	☐	☐	☐	☒	☐	☐
☐ INORGANIC	☐	☐	☐	☐	☐	☐
☐ THERMAL						
☐ NOISE						

PROCESS DESCRIPTION

Radial arm skimmers are used with circular settling tanks. They are designed mostly for the removal of floating solids, greases and scum and are generally used only where the expected volume of skimmings is small. Tank diameters may be much as 300 feet. The collector mechanism is normally one or two skimming arms with hinged blades at the other end. Fixed blades or deflectors on the centerward part of the boom move floating material slowly toward the rim of the tank where the hinged blades eventually sweep it into one or more scum boxes which are fixed to the outer rim.

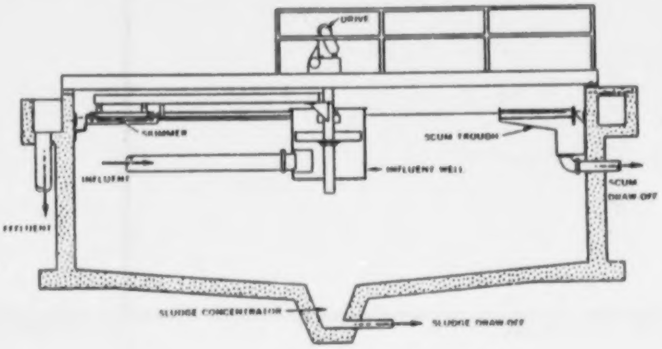


Figure 1. RADIAL ARM SKIMMER(1)

The construction of radial arm skimmers is variable with respect to the method of supporting the skimmer arm, and the following four major types are used:

1. Pier supported. The most common arrangement is probably the center pier support. The radial arm boom pivots about a pier built in the center of the tank. The pier supports the drive mechanism, collector arms, influent well, and one end of a fixed access bridge.

2. Bridge supported. This is the type illustrated in Figure 1. The skimmer arm is driven by a torque tube mechanism suspended from the center of a bridge across the tank. Because the bridge must span the entire tank, this system is limited to smaller tank diameters.

3. Traveling bridge supported. A radial bridge member is supported at one end by a pivot mechanism on the center pier, and at the other end by a motor-driven traveling carriage mechanism which traverses the circumference of the tank. The skimmer is suspended from the traveling bridge arm.

4. Rake supported. Any of the above three arrangements may be used to support a sediment rake. A surface skimmer can then be attached to the rake by vertical support members.

APPLICATION RANGE

Radial arm skimmers are normally used only where small volumes of skimmings are expected. The width of the scum trough is only a fraction of the radius and not all floating material will be removed in a single pass.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

OPERATING EFFICIENCIES

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Walker Process Division, Chicago Bridge & Iron Co.
Envirex Division, Rexnord
Ecodyne
Carborundum Co.
Eviro-Systems Division, Zurn Industries, Inc.
Environmental Elements Division, Koppers Co.
Dorr-Oliver, Inc.
General Filter Co.
Infilco-Degremont, Inc.

REFERENCES

1) Product Bulletin, Walker Process Division, Chicago Bridge & Iron Co.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil Skimmers)
SPECIFIC DEVICE OR PROCESS Rotating Disc Skimmer	**NUMBER** 2.1.6.12

POLLUTANTS CONTROLLED	**AIR** GASES	**AIR** PARTICULATES	**WATER** DISSOLVED	**WATER** SUSPENDED	**LAND** LEACHABLE	**LAND** FUGITIVE
☒ **ORGANIC**	☐	☐	☐	☒	☐	☐
☐ **INORGANIC**	☐	☐	☐	☐	☐	☐
☐ **THERMAL**						
☐ **NOISE**						

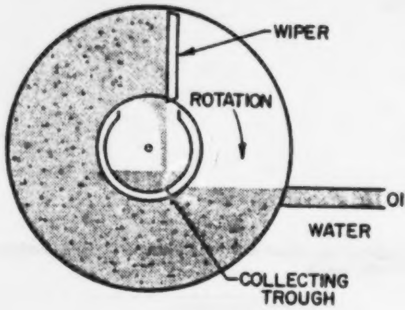


Figure 1. ROTATING DISK SKIMMER

PROCESS DESCRIPTION

The rotating disc skimmer takes advantage of the adherence of oils to a non-wetted solid surface and the ability of an oil-wetted surface to shed water. Shown in Figure 1 is a disc immersed to about one third its diameter in oil-covered water and rotating in a clockwise direction. As any point on the disc enters the fluid, the oil adheres to it and remains during the submerged portion of rotation. When that point reaches the liquid's surface, the oil remains on the disc and the water runs off. A stationary wiper moves oil from both sides of the disc into a takeoff channel from which it flows or is pumped to a storage tank.

Various models are available with plastic, aluminum or stainless steel discs. As many as 86 discs per unit with diameters up to 48 inches may be obtained. Either fixed or floating installations may be used.

The design of these skimmers makes them particularly invulnerable to clogging by debris.

APPLICATION RANGE

Effective in wide range of viscosities -- API 11° to API 48°. Oil recovery capacities of various makes and models range from less than one to forty gpm for refinery models. Models for offshore oil spill recovery have capacities to 40,000 bbl/day or more. Works with sandy oil from secondary recovery projects.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

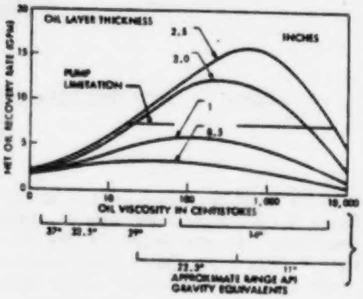
Oil Recovery Rate, gpm	Cost 1977
1	$2,000
3	3,000
6	5,000
12	9,000
25	13,000
50	20,000

Approximate costs, based on averages of several manufacturers.

OPERATING COSTS

Maximum Oil Recovery Rate, gpm	Horsepower, elec.
1/2	1/2
1	1/2
4	1/2
12	1
40	7

OPERATING EFFICIENCIES



Water carryover is approximately 5% of the recovered oil volume. Not affected by water level variations of a few inches. Oil recovery rate affected by viscosity and thickness of oil layer as shown for a typical model(1). About 95% of the oil encountered will be captured per pass.

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER/SUPPLIER

Marine Construction & Design Co.
Lockheed Missiles & Space Co.
Lowe Engineering Co.
Centri-Spray Corp.

REFERENCES

1) Lockheed Missiles & Space Co., Product Bulletin

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil Skimmers)
SPECIFIC DEVICE OR PROCESS Slotted Pipe Skimmer	**NUMBER** 2.1.6.13

POLLUTANTS CONTROLLED		**AIR**		**WATER**		**LAND**	
		GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
☒	**ORGANIC**	☐	☐	☐	☒	☐	☐
☐	**INORGANIC**	☐	☐	☐	☐	☐	☐
☐	**THERMAL**						
☐	**NOISE**						

PROCESS DESCRIPTION

One of the simplest of all skimmers, the slotted pipe is widely used in municipal and industrial waste treatment systems. It consists of a pipe installed at the water surface and perpendicular to the direction of water flow. Numerous slots are cut in one side of the pipe. When the pipe is rotated so that the lower edge of the slots is just below the water surface, any floating oil or solids will flow into the pipe and out the open end. The pipe revolves in and is supported at each end by a collar. Rotation of the pipe, to adjust the depth of cut for skimming, can be accomplished manually or with a motor drive. Pipe diameters range from 8 to 20 inches. Diameter is governed by the variation in liquid level, basin width and travel length of skimmings in the pipe.

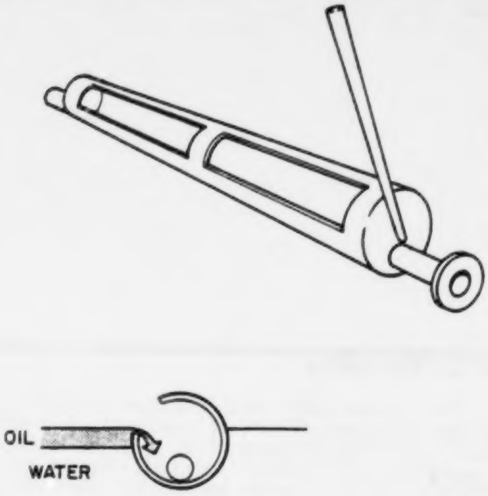


Figure 1. SLOTTED PIPE SKIMMER

These skimmers are often installed at the front of an API separator. Materials of construction may be metal, plastic or fiberglass.

By setting the skimming edge slightly above the maximum water level when no oil is present (A in Figure 1), only oil will be skimmed. This means that during less than maximum flow conditions a thick layer will accumulate before skimming takes place (B in Figure 1). With suitable instrumentation, automatic operation to vary depth of cut with thickness of oil layer is possible.

APPLICATION RANGE

The properties of the pollutant layer are unimportant, thus non-adsorbing oils or solids will also be removed just as effectively as the more common petroleum products. Can be made to handle any desired oil flow rate.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Costs are variable, depending on materials and details of installation. As an example, a 10-inch skimmer 12 feet long can cost from $1100 to $5300 for a manually operated version and $7800 for a motor-operated model (1977).

OPERATING COSTS

Operating costs are generally negligible. However, if manual operation is used in a system with variable flow periodic checks of oil level and skimmer setting are necessary.

OPERATING EFFICIENCIES

For a given water depth and pipe rotation, a constant thickness of surface layer will be removed regardless of the presence of oil. Close adjustment to operating conditions will normally result in a mixture of about 80% water and 20% oil when all oil is to be removed. If a thick layer of oil can be tolerated, the skimmer can be set to skim oil only.

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Rex Chainbelt, Inc.
AFL Industries, Inc.
Environmental Equipment Division, FMC Corp.
Walker Process Division, Chicago Bridge & Iron Co.
Jeffrey Manufacturing Division, Dresser Industries, Inc.

REFERENCES

1) Product Bulletin, AFL Industries, Inc.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil Skimmers)
SPECIFIC DEVICE OR PROCESS Spiral Skimmer	**NUMBER** 2.1.6.14

POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
	GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
☒ **ORGANIC**	☐	☐	☐	☒	☐	☐
☐ **INORGANIC**	☐	☐	☐	☐	☐	☐
☐ **THERMAL**						
☐ **NOISE**						

PROCESS DESCRIPTION

Spiral skimmers are used in rectangular settling tanks where large volumes of floating materials are to be removed. Spiral blades, similar to those in a push-type lawn mower, revolve to lift floating material from the water surface and drop it into a trough located immediately behind the blade. Usually only one or two blades are present and a rubber wiper strip is attached to the edge of the blade. The wiper strip makes contact with a curved metal or concrete beach to assure positive pickup. As the skimmer turns, the blades push scum up the beach and over the back edge where it drops into a scum trough.

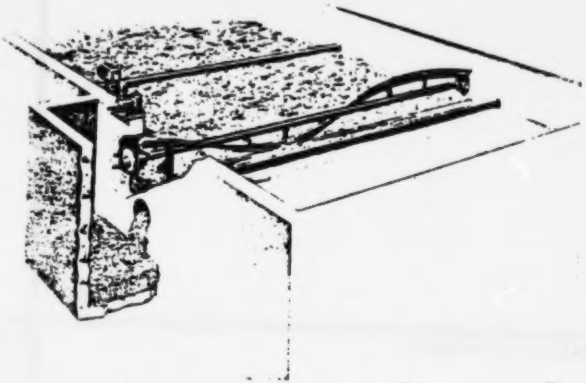


Figure 1. SPIRAL SKIMMER(1)

APPLICATION RANGE

Although used to remove floating oils and grease, spiral skimmers are primarily designed to remove light, frothy scums which would not, of their own accord, flow over a weir.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

OPERATING EFFICIENCIES

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Environmental Equipment Division, FMC Corp.
Rex Chainbelt, Inc.
Walker Process Division, Chicago Bridge & Iron Co.
Jeffrey Manufacturing Division, Dresser Industries, Inc.

REFERENCES

1) Product Bulletin, Rex Chainbelt, Inc.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil Skimmers)
SPECIFIC DEVICE OR PROCESS Suction Type Skimmers	**NUMBER** 2.1.6.15

POLLUTANTS CONTROLLED		**AIR** GASES		**AIR** PARTICULATES		**WATER** DISSOLVED		**WATER** SUSPENDED		**LAND** LEACHABLE		**LAND** FUGITIVE
x	**ORGANIC**						x					
	INORGANIC											
	THERMAL											
	NOISE											

PROCESS DESCRIPTION

Suction type skimmers operate on the same principle as a vacuum cleaner. They are used almost exclusively for cleaning up infrequent oil spills from the surface of settling ponds, basins, holding tanks, etc.

A lightweight suction head is connected by means of a vacuum hose to a positive displacement pump or vacuum tank. The suction head may be free floating or may be attached to a hand-held wand.

The suction intake is a fixed orifice and is simply positioned at the water surface. No discrimination is made between water and oil.

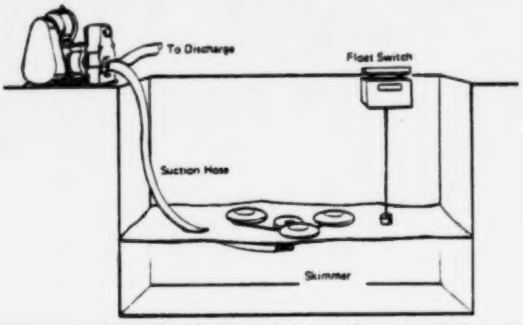


Figure 1. SUCTION TYPE SKIMMER INSTALLATION(1)

APPLICATION RANGE

Applicable to all types of oil, but some models may not be suitable for use with very viscous materials.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Skimmer heads alone can be very inexpensive. The major cost of a system is the pump or vacuum source used. Cost of these items is highly variable.

OPERATING COSTS

OPERATING EFFICIENCIES

Although a suction skimmer will eventually remove all traces of oil, it becomes inefficient when only a small amount of oil is present. Under these conditions a large ratio of water to oil is pumped.

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Acme Products Co.
Mapco, Inc.
Megator Corp.
Slickbar, Inc.
Skim, Inc.
Vac-U-Max

REFERENCES

1) Product Bulletin, Megator Corp.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil Skimmers)	
SPECIFIC DEVICE OR PROCESS Traveling Bridge Skimmer		**NUMBER** 2.1.6.16

POLLUTANTS CONTROLLED	**AIR** GASES	**AIR** PARTICULATES	**WATER** DISSOLVED	**WATER** SUSPENDED	**LAND** LEACHABLE	**LAND** FUGITIVE
X **ORGANIC**	☐	☐	☐	X	☐	☐
☐ **INORGANIC**	☐	☐	☐	☐	☐	☐
☐ **THERMAL**						
☐ **NOISE**						

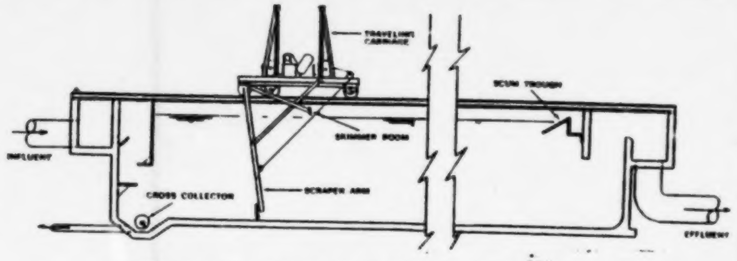


Figure 1. TRAVELING BRIDGE SKIMMER (1)

PROCESS DESCRIPTION

The traveling bridge skimmer is used for very large rectangular basins handling large volumes of wastes. A bridge structure spans the basin and rests on a traveling carriage at each end. Usually both a skimmer and a sludge scraper are mounted on the bridge as shown in Figure 1. The bridge traverses the basin in one direction with the scraper suspended while the skimmer forces oil and floating solids into the scum trough. On the return run the skimmer is raised above the surface and the sludge scraper is lowered to the bottom to scrape sediment and sludge to the opposite end of the tank.

Operation can be made continuous or periodic in any type of timed cycle.

The traveling bridge principle is also used with circular tanks, with the bridge rotating continuously in one direction.

APPLICATION RANGE

Traveling bridge collectors can be made to span tanks 100 ft wide and more. Virtually any type of floating oil, grease or solids can be skimmed off.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

OPERATING EFFICIENCIES

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Walker Process Division, Chicago Bridge & Iron Co.
FMC Corp.
Eviro Systems Division, Zurn Industries, Inc.
Environmental Elements Division, Koppers Co.
Aqua-Aerobic Systems, Inc.
Peabody Welles

REFERENCES

1) Product Bulletin, Walker Process Division, Chicago Bridge & Iron Co.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil Skimmers)
SPECIFIC DEVICE OR PROCESS Vortex Oil Skimmer	**NUMBER** 2.1.6.17

POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
	GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
X **ORGANIC**				X		
INORGANIC						
THERMAL						
NOISE						

PROCESS DESCRIPTION

When a volume of water is caused to rotate by any means, a vortex is formed at the center of rotation. The cavity formed is similar to a paraboloid (Figure 1), with decreasing depth at increasing distances from the center. The depth of the vortex is proportional to the speed of rotation. A covering of oil or any other polluting material lighter than water and not miscible with it, under the influence of a vortex, forms a pocket of the pollutant (Figure 1). The depth of this pocket (dependent on density) is such that the equilibrium of forces is not modified at the oil-water interface. This vortex phenomenon provides the ability to concentrate a superficial layer of oil only a fraction of an inch thick into a sufficient volume for pumping by classical systems. The pocket of oil being pumped is replenished continously from the area surrounding the vortex.

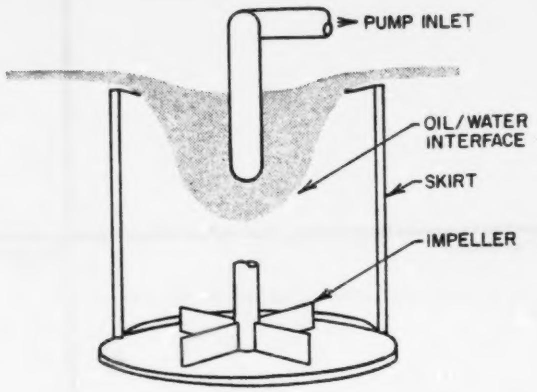


Figure 1. VORTEX OIL SKIMMER

The depth of the oil pocket formed by the vortex is a function of density and increases inversely with the difference between the densities of water and the oil.

A zero-pitch impeller creates the vortex oil pocket in which a pump inlet hose is placed for oil removal. Operation of the system is monitored and controlled by an electronic sensor which detects the presence of oil in the pocket.

Adjustable time delays can be provided in order to prevent unnecessary, rapid, on/off action associated with short pulses of oil. In operation, the impeller is left rotating continuously at a fixed speed in the order of 30 rpm (typical power drain is 1/2 HP in 50-100 gpm systems). When oil appears, the vortex pocket depth will increase and eventually oil will cover the sensor located below the pump intake. Following the pre-set time delay, the pump is turned on and continues to operate as long as sufficient oil is present to replenish the pocket. When the surface oil is removed, the pocket depth decreases and water level covers the sensor causing it to turn off the pump. Transient changes of oil and water due to wave motion or short slugs of oil, debris, etc. are ignored by means of the built-in time delays.

If oil is only infrequently present on the surface, a second sensor may be used near the surface to sense the presence of floating oil. The output of this sensor is used to activate the impeller motor, thus generating the vortex pocket. Since oil is continuously drawn into the vortex, continuous transversing of the oil spill is not required for recovery. Due to the gyroscopic stability of the rotational vortex, the system is unaffected by small surface chop or transient surface disturbance due to wind or other factors.

APPLICATION RANGE

Models available with recovery rates of 10 to 1000 gpm. Since operating principle is based only on density difference, oil of any viscosity can be recovered.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Oil Recovery Rate, gpm	Cost 1977
10	$ 8,000
50	18,000
100	28,000
1000	100,000

Costs vary substantially, depending on details of floats, pumps, controls.

OPERATING COSTS

Oil Recovery Rate, gpm	Horsepower
50	5

OPERATING EFFICIENCIES

Typically yields less than 5% water in recovered hydrocarbons.

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Intex, Inc.

REFERENCES

1) Intex, Inc., Product Bulletin

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil-Water Separators)
SPECIFIC DEVICE OR PROCESS API Oil Separator	**NUMBER** 2.1.7.1

POLLUTANTS CONTROLLED	AIR GASES	AIR PARTICULATES	WATER DISSOLVED	WATER SUSPENDED	LAND LEACHABLE	LAND FUGITIVE
x ORGANIC				x		
INORGANIC						
THERMAL						
NOISE						

PROCESS DESCRIPTION

An API separator consists of a rectangular settling basin designed in accordance with the standards developed by the American Petroleum Institute(2). It is generally constructed of concrete. Water flows horizontally through the basin while free oil particles slowly rise to the surface. A typical API separator is shown in Figure 1. Dual flow channels as shown allow operation of one half while the other is shut down for maintenance.

The major elements of an API separator, listed in the order encountered by the waste stream include a preseparator flume, trash rack, forebay, oil skimmer, oil retention baffle, diffusion device, settling basin, oil skimmer, oil retention baffle, and effluent weir. The preseparator flume serves to reduce flow velocity and allow collection of trash and floating oil. An oil skimmer (any of various types) may be placed either here or in the forebay or both. Downstream of the first oil baffle is a diffusion device, such as a vertical slot baffle or reaction jet, which serves to reduce flow turbulence and distribute flow equally over the channel cross section. Typically, as shown in Figure 1, a chain and flight combination oil- and sludge-moving device is used in the separator channel. A final oil skimmer (any of several types such as slotted pipe, adsorbent drum, floating weir, etc.) is located in front of the last oil retention baffle.

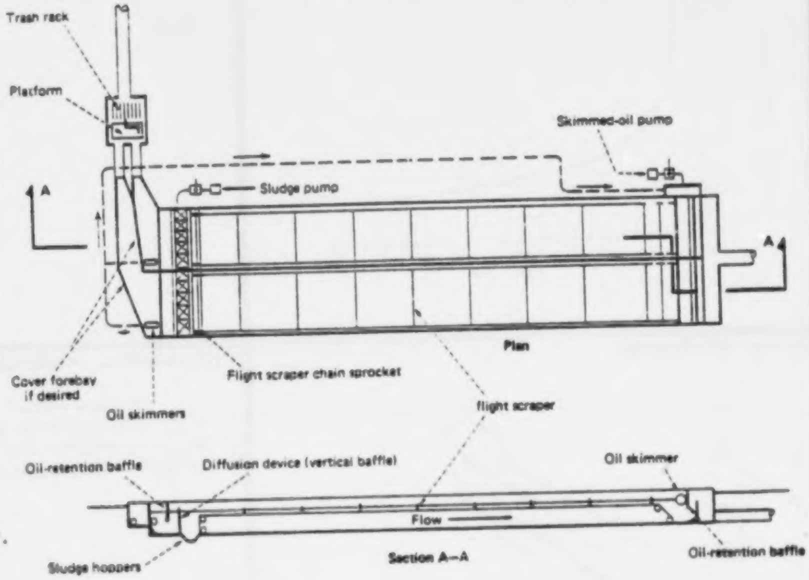

Trash rack
Platform
Skimmed-oil pump
Sludge pump
A
A
Plan
Cover forebay if desired
Oil skimmers
Flight scraper chain sprocket
flight scraper
Oil-retention baffle
Diffusion device (vertical baffle)
Oil skimmer
Flow
Sludge hoppers
Section A—A
Oil-retention baffle

Figure 1. API OIL SEPARATOR(1)

APPLICATION RANGE

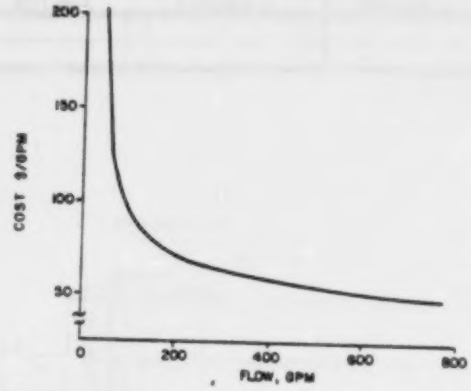
API separators are designed to order for any wastewater flow rate. Operation of skimmers may be susceptible to weather conditions.

The API separator is designed to allow oil globules of 0.015 cm diameter or larger to rise from the bottom of the separator to the surface before the last oil retention baffle is reached.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Refinery API separators were estimated to cost approximately $40,000 per MGD of capacity in 1965(4). 1976 costs for pre-packaged units (not including installation) are given below.



OPERATING COSTS

Pre-1965 (year unknown) maintenance and operating costs as a function of capacity have been reported(3) as:

Flow (MGD)	M&O Cost ($/Yr)	Cost ($/MGD)
3.0	23,000	7,667
7.5	36,000	4,800
15.0	55,000	3,667

OPERATING EFFICIENCIES

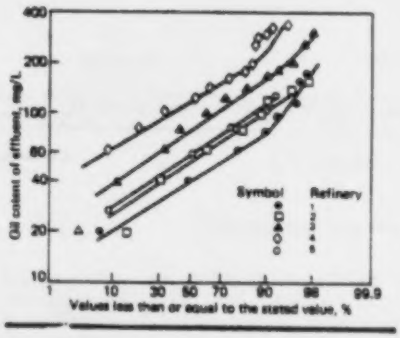


Figure 2. PERFORMANCE OF API SEPARATORS(1)

ENVIRONMENTAL PROBLEMS

Limited removal of emulsified or soluble oil. When volatile oils are being recovered, large covers may be required to limit evaporative losses in forebay and separator sections.

NOTES

MANUFACTURER / SUPPLIER

Inland Environmental

REFERENCES

1) Ford, D. L., & Elton, R. L., "Removal of Oil & Grease from Industrial Wastewaters", Chemical Engineering, October 17, 1977.
2) American Petroleum Institute, Manual on Disposal of Refinery Wastes, Chapt. 5,6, 1969.
3) Patterson, J. W., Wastewater Treatment Technology, Ann Arbor Science, 1975.
4) Beychok, M. R., Aqueous Wastes from Petroleum and Petrochemical Plants, Wiley, 1967.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil-Water Separators)	
SPECIFIC DEVICE OR PROCESS Circular Settling Basin		**NUMBER** 2.1.7.2

POLLUTANTS CONTROLLED	**AIR** GASES	**AIR** PARTICULATES	**WATER** DISSOLVED	**WATER** SUSPENDED	**LAND** LEACHABLE	**LAND** FUGITIVE
☒ **ORGANIC**	☐	☐	☐	☒	☐	☐
☐ **INORGANIC**	☐	☐	☐	☐	☐	☐
☐ **THERMAL**						
☐ **NOISE**						

PROCESS DESCRIPTION

Circular oil-water separators have been used in the oil industry. These units follow the design of a circular clarifier with a central influent entrance and peripheral effluent discharge. A dual system is shown in Figure 1, where the large unit handles dirty or oily water and the smaller unit accepts a clean water stream. Although test data indicate that reasonable oil removal may be achieved, there are no design standards as for the API separator, and performance can be quite variable.

Circular units may also be designed with peripheral feed instead of central feed.

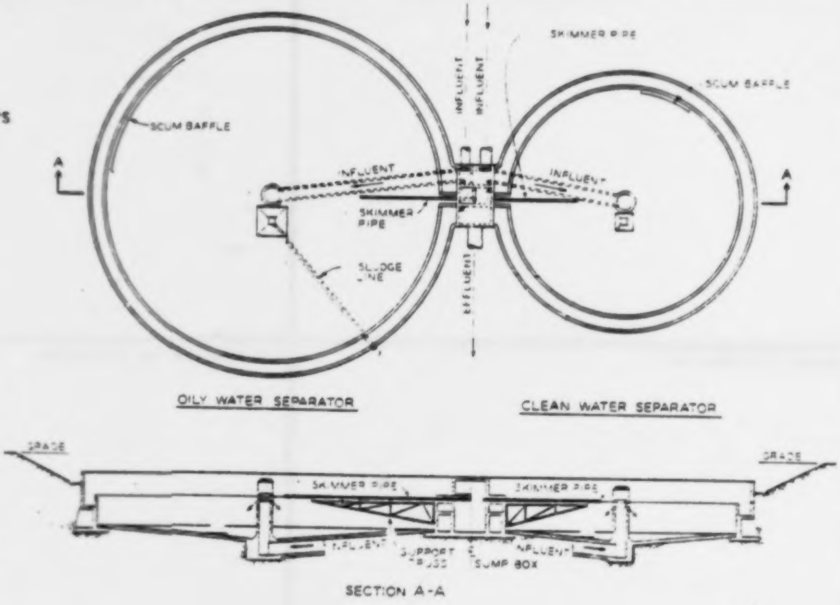

SKIMMER PIPE
SCUM BAFFLE
INFLUENT
INFLUENT
SCUM BAFFLE
A
INFLUENT
INFLUENT
A
SKIMMER PIPE
SLUDGE LINE
EFFLUENT
OILY WATER SEPARATOR
CLEAN WATER SEPARATOR
GRADE
GRADE
SKIMMER PIPE
SKIMMER PIPE
INFLUENT
SUPPORT TRUSS
SUMP BOX
INFLUENT
SECTION A-A

Figure 1. CIRCULAR SEPARATOR(1)

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS	**OPERATING COSTS**
OPERATING EFFICIENCIES	**ENVIRONMENTAL PROBLEMS** **NOTES**

MANUFACTURER / SUPPLIER

REFERENCES

1) American Petroleum Institute, Manual on Disposal of Refinery Wastes, Volume on Liquid Wastes, Chapt. 5, 1969.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil-Water Separators)
SPECIFIC DEVICE OR PROCESS Rectangular Settling Basins	**NUMBER** 2.1.7.3

POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
	GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
x **ORGANIC**				x		
INORGANIC						
THERMAL						
NOISE						

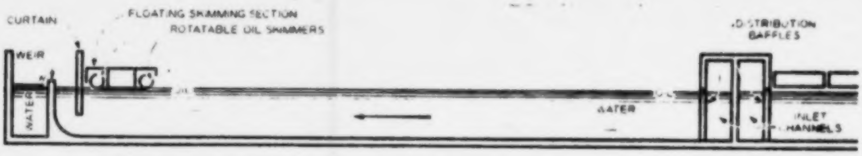


Figure 1. RECTANGULAR OIL-WATER SEPARATING BASIN

PROCESS DESCRIPTION

Gravity separation in a rectangular tank or settling basin is a common method of separating oil from wastewater. Separation of oil and sediment are accomplished at the same time. A set of specific design standards for rectangular separators is the API separator, but other design approaches are feasible. The basic features of a settling basin, as seen in Figure 1, include a flow distributor at the inlet, a long, relatively shallow basin; an oil retention weir or curtain and a water overflow weir. Oil which accumulates on the surface is removed by any of a large variety of surface skimming equipment and techniques.

A settling basin will not separate soluble oils or emulsions. The applicability of gravity settling to a particular waste stream may be tested by means of API Method 734: Determination of Susceptibility to Oil Separation.

Separators may be operated as batch vats, or as continuous flow-through basins, depending upon the volume of waste to be treated.

APPLICATION RANGE

Although no limits are established, the specific gravity of oil to be separated must be enough different from water to allow globules to rise by buoyant forces in a practical distance. Rise rate is reduced at lower temperatures, being one half as rapid at 40° as at 90°F.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

OPERATING EFFICIENCIES

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Enviro-Systems Division, Zurn Industries
Peabody Welles
Aqua-Aerobic Systems
AFL Industries

REFERENCES

1) American Petroleum Institute, Manual on Disposal of Refinery Wastes, Volume on Liquid Wastes, Chapt. 6, 1969.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Setting Sedimentation (Oil-Water Separators)
SPECIFIC DEVICE OR PROCESS Wash Tanks and Skim Tanks	**NUMBER** 2.1.7.4

	POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
		GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
☒	**ORGANIC**	☐	☐	☐	☒	☐	☐
☐	**INORGANIC**	☐	☐	☐	☐	☐	☐
☐	**THERMAL**						
☐	**NOISE**						

PROCESS DESCRIPTION

Wash tanks or skim tanks are used as gravity separation devices in oil field production facilities, in refineries and bulk terminals. A representative configuration, with diameter approximately equal to height, is shown in Figure 1. Many different types of flow spreaders or baffles are used in an attempt to distribute flow evenly over the cross section of the tank and thereby achieve a long and uniform residence time for all portions of the flow stream. A typical spreader is shown on the bottom of the tank in Figure 1. Tank sizes used are almost infinitely variable.

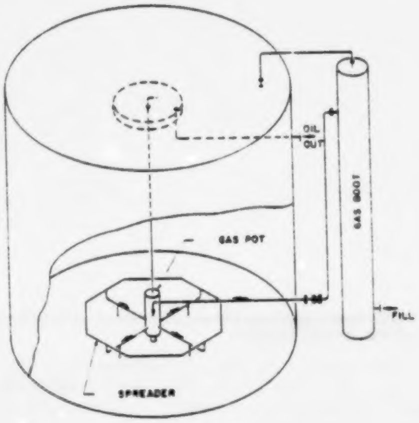


Figure 1 WASH TANK WITH SPREADER(1)

APPLICATION RANGE

Used widely in many different applications. Can accommodate either high or low oil/water ratios in feed.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Capital costs may be assumed to be approximately the same as for an unmodified tank of the same volume. Tank volumes are normally sized to give a calculated residence time of several hours.

OPERATING COSTS

Usually negligible

OPERATING EFFICIENCIES

Efficiency is highly dependent on the design of baffles and spreaders. Most units observed in the field are relatively inefficient because of extreme short circuiting of both oil and water in the flow pattern. The measured mean residence time may be considerably less than 10% of the calculated residence time.

ENVIRONMENTAL PROBLEMS

Highly variable performance from one design to another. Relatively low average separation efficiency.

NOTES

MANUFACTURER / SUPPLIER

REFERENCES

1) Zemel, B., Bowman, R. W. "Residence Time Distribution in Gravity Oil-Water Separation," J. Pet. Tech., Feb. 1978, Copyright SPE-AIME.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil-Water Separators)		
SPECIFIC DEVICE OR PROCESS Gravity Displacement Separator		**NUMBER** 2.1.7.6	

POLLUTANTS CONTROLLED	**AIR** GASES	**AIR** PARTICULATES	**WATER** DISSOLVED	**WATER** SUSPENDED	**LAND** LEACHABLE	**LAND** FUGITIVE
☒ **ORGANIC**	☐	☐	☐	☒	☐	☐
☐ **INORGANIC**	☐	☐	☐	☐	☐	☐
☐ **THERMAL**						
☐ **NOISE**						

PROCESS DESCRIPTION

The gravity displacement separator is a horizontal steel vessel divided into three compartments, including the separation chamber, an oil sump and a water sump. An oil-water mixture flows into the separation chamber (Figure 1), where oil rises to the surface and water sinks to the bottom due to gravitational forces and the differences in specific gravity. Oil rises to the interface and displaces an equivalent volume of oil into the oil sump. Oil-free water flows to the opposite end of the separation chamber from the inlet, then through a hydraulic trap and overflows into a third chamber, which is the water sump. This scheme allows the separator to operate over an infinite range of inlet concentrations (from all water to all oil) without the use of skimming devices or power other than for pumping (pumping required only where gravity flow from separator is not possible). If the oil pump fails, oil will accumulate in the separation chamber and the interface will drop. No oil will be released in the water stream until all water ballast in the separation chamber has been displaced. This feature allows the separator to function as a holding tank for spills.

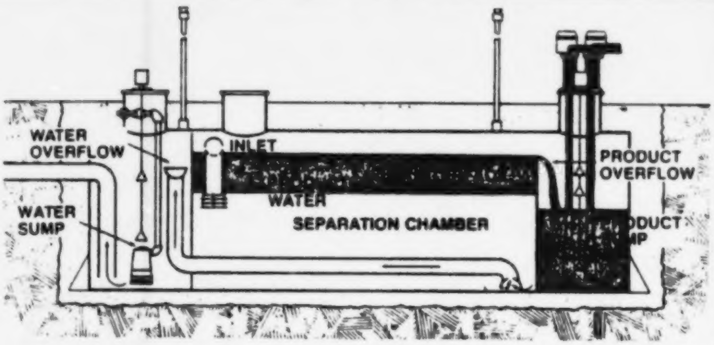


Figure 1. GRAVITY DISPLACEMENT SEPARATOR(1)

Similar design considerations may be used in a variety of other applications(2).

APPLICATION RANGE

Designed for spill control protection in petroleum handling facilities. If precipitation runoff is handled, the maximum drainage area recommended is 10,000 sq ft.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Tank Volume	Maximum Water Flow	Approximate Installed Cost, 1977
3,000 gal	50 gpm	$13,000
5,000 gal	200 gpm	$20,000
10,000 gap	400 gpm	$25,000

OPERATING COSTS

OPERATING EFFICIENCIES

Test data for water-kerosene, 10,000 gal tanks(1).

Water Flow	Effluent Oil
50 gpm	0-50 ppm
200 gpm	less than 10 ppm
400 gpm	less than 10 ppm

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Enquip, Inc.
Korest-Peterson Co.

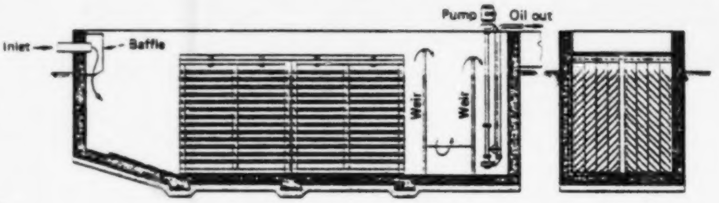
REFERENCES

1) Product Bulletin, Enquip
2) Miranda, J. G., "Sump Design for Oil/Water Separators", Chem, Engr., November 24, 1975.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil-Water Separators)
SPECIFIC DEVICE OR PROCESS Parallel Plate Interceptor	**NUMBER** 2.1.7.7

POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
	GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
x **ORGANIC**				x		
INORGANIC						
THERMAL						
NOISE						

PROCESS DESCRIPTION



Side View

Cross Section

Figure 1. PARALLEL PLATE INTERCEPTOR(1)

The parallel plate interceptor works on the principle of reducing the distance that a particle of oil must travel before reaching a collecting surface. The collecting surface consists of a number of parallel plates set at an angle of approximately 45 degrees to the horizontal and spaced a few centimeters apart. The direction of water flow is parallel to the plane of the plates (Figure 1). As the oil-bearing water flows between the plates, oil droplets coalesce on the under sides of the plates. As the drops grow in size, they creep upward along the plates until they eventually reach the surface and form a floating layer in the separator. The plates establish laminar flow conditions through the plate pack and at the same time reduce the distance that individual oil drops must rise before being trapped and coalesced.

While oil droplets collect on the underside of the plates, solid particles collect on the top of each plate and then slide down to bottom. By reducing the travel distance for oil droplets, a PPI can be made much smaller, for an equivalent degree of separation, than an API separator. Figure 1 shows a PPI designed to allow automatic oil recovery without skimmers and with only one pump, by using two weirs of different heights.

The smaller the distance between the plates, the greater the separation efficiency will be. However, as this distance is reduced, problems of clogging may appear. A range of 2 to 10 cm may be typical(1).

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

OPERATING EFFICIENCIES

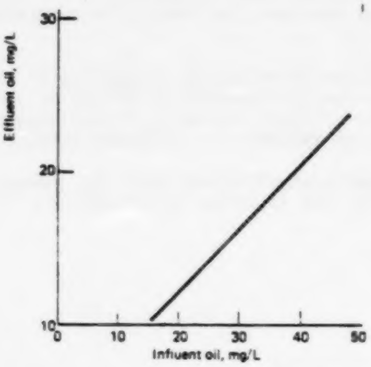


Figure 2. PPI PERFORMANCE(2)

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Facet Enterprise, Inc.
Butterworth Systems, Inc.

REFERENCES

1. Miranda, J. G., "Designing Parallel-Plates Separators", Chem. Engr., January 31, 1977.
2. Ford, D. L., & Elton, R. L., "Removal of Oil Grease from Industrial Wastewaters", Chem. Engr., October 17, 1977.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil-Water Separators)
SPECIFIC DEVICE OR PROCESS Corrugated Plate Interceptor	**NUMBER** 2.1.7.8

POLLUTANTS CONTROLLED		**AIR**				**WATER**				**LAND**			
		GASES		**PARTICULATES**		**DISSOLVED**		**SUSPENDED**		**LEACHABLE**		**FUGITIVE**	
X	**ORGANIC**							X					
	INORGANIC												
	THERMAL												
	NOISE												

PROCESS DESCRIPTION

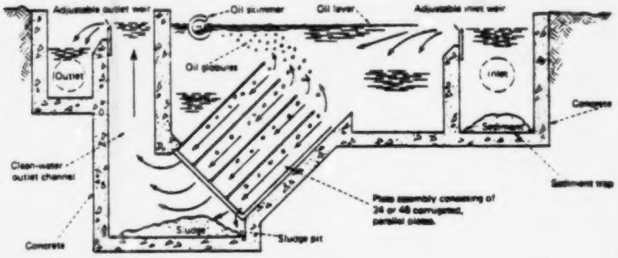


Figure 1. CORRUGATED PLATE INTERCEPTOR(1)

The corrugated plate interceptor (CPI) is similar in design to the parallel plate interceptor (Device 2.1.6.20). A CPI consists of packs of corrugated plates (usually 10 to 50 plates on the order of 0.05 in. thick) which are mounted parallel to each other and set 1/2 to 2 in. apart. The plate pack is fixed with the corrugations at an angle of 40 to 60 degrees from the horizontal. Flow may be either downward, following the corrugations, as shown in Figure 1, or horizontally across the corrugations. In either case, laminar flow conditions are established within the pack. The close spacing of the plates reduces the distances that oil droplets must rise to be collected. Droplets float toward the top of the corrugations and other follow the corrugations up the incline of the plate to the water surface. In the tops of the corrugations a small rivulet of oil will form. The high oil concentration at this point favors coalescence, which reduces re-entrainment of oil.

Simultaneously with oil accumulating on the bottom surfaces of the corrugated plates and moving upward, sediment will accumulate on the top surfaces and move downward. Minimum plate spacing is determined from clogging considerations.

Plates lengths up to 10 feet have been used, and plate packs up to 40 feet long. Plate-type separators will require only 15-20% as much space for installation as an API separator with equivalent oil separating efficiency. The compact size makes it easier to provide vapor-tight covers when volatile oils are handled. It is possible to upgrade the operation of existing conventional rectangular or circular settling basins by installing plate packs.

Materials of construction may be varied to suit the application, including carbon steel, galvanized steel, stainless steel or fiber reinforced plastic.

A CPI plate pack may be used in conjunction with a flotation system to improve the efficiency of both.

APPLICATION RANGE

Can be designed for any flow rate. Suitable construction materials available for any type of corrosive service. Retention times are normally in the range of 3-15 minutes. Large changes in oil/water ratio can be accommodated.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Costs are variable depending on materials of construction and specific gravity of oil being separated. Typical cost for a wastewater flow of 500 gpm could be on the order of $30,000 (1978).

OPERATING COSTS

The corrugated plate interceptor has no moving parts, therefore very low operating and maintenance costs.

OPERATING EFFICIENCIES

Typical Refinery Data

Influent oil and grease	Effluent oil and grease
150-500 mg/L	50-86 mg/L
500-700 mg/L	178-330 mg/L

Effiency depends on oil particle size and on the difference in specific gravity between oil and water, therefore on the type of oil being recovered. Effluent concentrations as low as 10-20 mg/L can be reached.

ENVIRONMENTAL PROBLEMS

Little or no removal of emulsified or soluble oil.

NOTES

MANUFACTURER / SUPPLIER

Pielkenroad Separator Co.
Monarch Separators
McTighe Industries Inc.
Heil Waste Treatment, Lancy Division,
Dart Environmental & Services

REFERENCES

1) Ford, D. L., & Elton, R. L., "Removal of Oil and Grease from Industrial Wastewaters", Chem. Engrs., October 17, 1977.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil-Water Separators)
SPECIFIC DEVICE OR PROCESS Vertical Tube Coalescer	**NUMBER** 2.1.7.9

POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
	GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
X **ORGANIC**				X		
INORGANIC						
THERMAL						
NOISE						

PROCESS DESCRIPTION

In operation, the waste stream passes through and over a diffusing baffle into a separating chamber. A matrix of vertically-positioned polypropylene tubes intercepts the liquid, converting its flow. from turbulent to laminar. This causes the liquid to be more responsive to gravity separation.

The oleophilic nature of the plastic tube material also promotes separation. Small oil globules are attracted to it, attach to the surface, coalesce with other globules, increase in size and buoyancy, then break away to rise through the tubes to the top. Surface oil may be gravity skimmed and drained to a slop tank.

The effectiveness of the vertical tube coalescer arises from the large surface area available on the tubes.

From the separating chamber, the water flows under an oil retention baffle and into the outlet chamber.

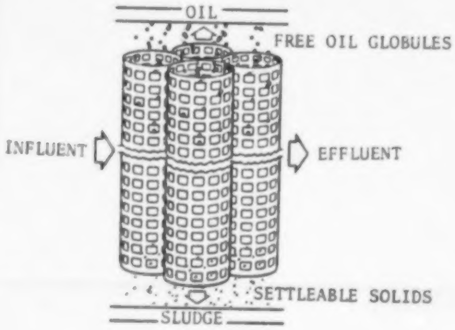


Figure 1. VERTICAL TUBE COALESCER PRINCIPLE(1)

APPLICATION RANGE

Modular units handle flows from 10 to 3,600 gpm.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

OPERATING EFFICIENCIES

Typical performance factors:

99% removal of tramp oil
Removal of globules larger than 20 microns
Effluent concentration 10 mg/l

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

AFL Industries

REFERENCES

1) Product bulletin, AFL Industries, Inc.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil-Water Separation)
SPECIFIC DEVICE OR PROCES Fibrous Media Coalescers	**NUMBER** 2.1.7.10

POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
	GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
☒ **ORGANIC**	☐	☐	☐	☒	☐	☐
☐ **INORGANIC**	☐	☐	☐	☐	☐	☐
☐ **THERMAL**						
☐ **NOISE**						

PROCESS DESCRIPTION

Gravity separation of finely dispersed or mechanically emulsified oil from water can be aided by passing the mixture through a fibrous media coalescing element. When water is the continuous or major phase, droplets of oil are attracted to and attach to the small diameter fibers. As additional droplets are captured, the individual droplets coalesce to form bigger drops, which eventually develop enough buoyancy to break loose and rise to the surface. The oil can then be recovered by surface skimmers or by means of pumps or valves actuated by level switches. Figure 1 illustrates a typical 3-stage system with flow from the inside to the outside of cylindrical coalescer cartridges. (Shown in the 2nd & 3rd stage).

The opposite to the above process occurs when small amounts of water are to be separated from large amounts of oil. In this case water droplets settle to the bottom.

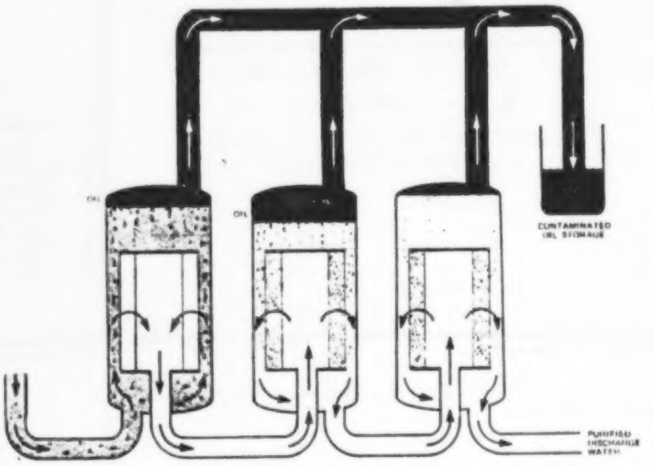


Figure 1. MULTI-STAGE FIBROUS MEDIA COALESCER(1)

Many different fibrous materials are used, including fiberglass, steel wool, nylon, teflon, polyolefins, polyamides, polyesters and excelsior. The fibers may be wound, packed or pressed into many different configurations including cylindrical, conical, plate, rope and bulk pack. The most common type is a cylindrical cartridge wound on a hollow tube.

Operation of fibrous coalescers is usually limited by solids accumulation. Solids buildup can blind off the surface, which gradually increases the pressure drop across the element until either the flow rate becomes insufficient or else the media is compressed to the point that it no longer functions as a coalescer. Typical solutions to this problem include pre-filtering stages (1st stage in above diagram), periodic backwashing of the coalescer elements, or the use of flow through coalescer elements.

The separation efficiency of coalescers can be quite variable depending on such factors as oil characteristics, degree of emulsion, droplet sizes, suspended solids, oil concentrations and fluctuations in flow. Coalescers can be disarmed by the presence of surfactants in the influent. Surfactants are surface-active agents, such as soaps, detergents, emulsifiers, etc. which interfere with the coalescing process.

APPLICATION RANGE

Usually stated to the effective provided specific gravity differential between oil and water is at least 0.08. Prepackaged units available for flows from 1 to 1500 gpm. The technique is readily adaptable to handling high pressure or high temperature streams. Gravity separation alone is effective for oil drops larger than 150 microns, thus coalescers are required only when smaller drops are present.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

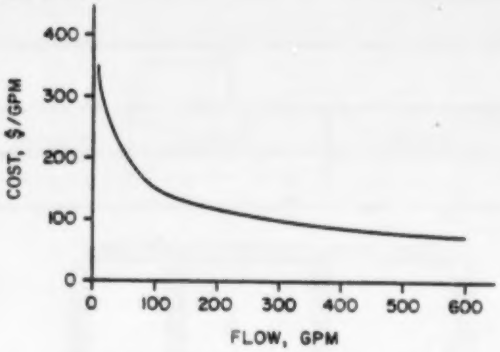


Figure 2. COST FOR TYPICAL 3 - STAGE SYSTEM WITH CONTROLS

OPERATING COSTS

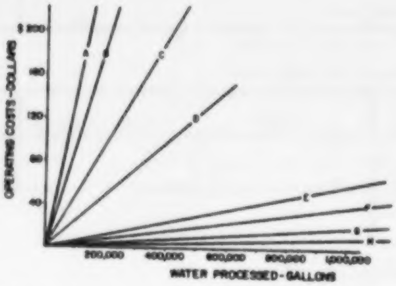


Figure 3. OPERATING COST COMPARISON(2)

A Standard Filter-Coalescer-30 ppm solids
B Standard Filter-Coalescer-20 ppm solids
C Standard Filter-Coalescer-10 ppm solids
D Standard Fliter-Coalescer- 5 ppm solids
E Flow-Through Coalescer Cartridge-30 ppm solids
F Flow-Through Coalescer Cartridge-20 ppm solids
G Flow-Through Coalescer Cartridge-10 ppm solids
H Flow-Through Coalescer Cartridge- 5 ppm solids

OPERATING EFFICIENCIES

Typical effluent concentrations are quoted in the range 5 to 10 ppm.

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

AFL Industries, Inc.
Facet Enterprises, Inc.
Kolar Filters, Inc.
Mapco, Inc.
Oil Mop, Inc.
Velcon Filters, Inc.
National Marine Service, Inc.
Butterworth Systems, Inc.

Harco Manufacturing Co.
Separation & Recovery Systems, Inc.
Inland Environmental

REFERENCES

1) Product Bulletin, Velcon Filters, Inc.
2) Product Bulletin, Mapco, Inc.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Settling, Sedimentation (Oil-Water Separation)
SPECIFIC DEVICE OR PROCESS Loose Media Coalescer	**NUMBER** 2.1.7.11

POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
	GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
x **ORGANIC**				x		
INORGANIC						
THERMAL						
NOISE						

PROCESS DESCRIPTION

Gravity separation of finely dispersed or mechanically emulsified oil from water can be aided by passing the mixture through a loose media coalescer. As the mixture flows through the porous bed, oil droplets are coalesced and rise to the surface. The oil can then be recovered by various arrangements of skimmers or weirs, or else by means of pumps or valves actuated by level switches. Types of media used include graded sand, plastic or resin beads.

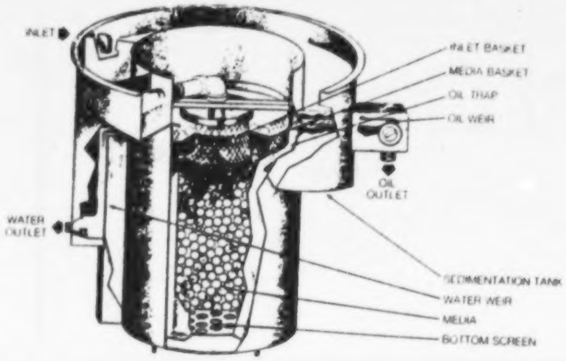


Figure 1. LOOSE MEDIA COALESCER(1)

Figure 1 illustrates a particular configuration. The oil water mixture flows into the sedimentation tank where the heavier particles settle. The sedimentation tank is independent of the separator tank and is fitted with a blowdown connection. The oil water mixture enters the inlet basket and then flows into the media where the free oil separates from the water at an accelerated rate. The water flows downward through the bottom screen, then up and over the water weir which creates a water table supporting the oil layer. The oil travels horizontally on top of the water into the oil trap and then over the adjustable oil weir which is set at a position slightly above the maximum water level.

Loose media coalescers should be less subject to problems of fouling and plugging by solids than are fibrous media coalescers. If these problems do arise, then pre-filtering or periodic back-washing of the media bed can be used.

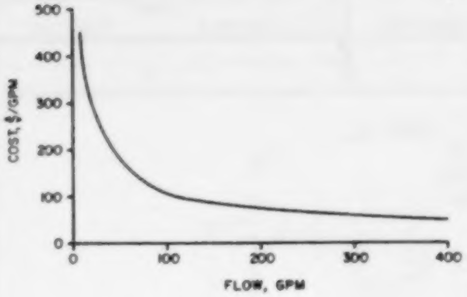
The separation efficiency of coalescers can be variable depending on such factors as oil characteristics, degree of emulsion, droplet sizes, suspended solids, oil concentrations and fluctuations in flow.

APPLICATION RANGE

A minimum specific gravity differential between oil and water of at least 0.05 is required. Oil viscosity up to 1000 centistokes. Modular units available to handle flows of 1 to 5000 gpm.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	40-800 °F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS



OPERATING COSTS

OPERATING EFFICIENCIES

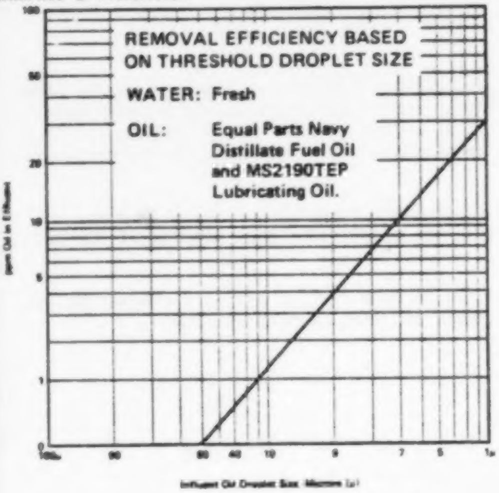


Figure 2. RESINOUS MEDIA COALESCER(2)

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Hyde Products, Inc.
Liquid Processing Systems, Inc.
C-E Natco, National Tank Co. Division
Harco Manufacturing Co.
Penco Division, Hudson Engineering Co.

REFERENCES

1) Product Bulletin, Hyde Products
2) Product Bulletin, Liquid Processing Systems

CLASSIFICATION
Liquid Treatment

GENERIC DEVICE OR PROCESS
Settling, Sedimentation (Oil-Water Separation)

SPECIFIC DEVICE OR PROCESS
Horizontal Plate Coalescer

NUMBER
2.1.7.12

POLLUTANTS CONTROLLED	AIR: GASES	AIR: PARTICULATES	WATER: DISSOLVED	WATER: SUSPENDED	LAND: LEACHABLE	LAND: FUGITIVE
☒ ORGANIC	☐	☐	☐	☒	☐	☐
☐ INORGANIC	☐	☐	☐	☐	☐	☐
☐ THERMAL						
☐ NOISE						

PROCESS DESCRIPTION

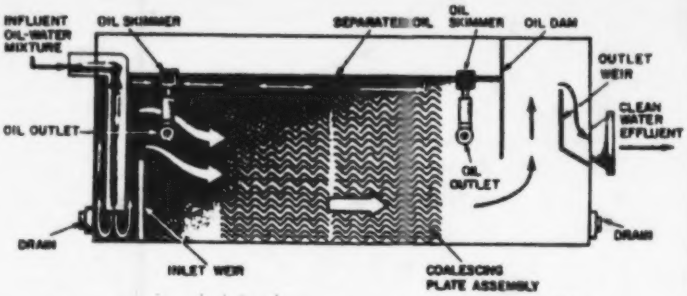


Figure 1. HORIZONTAL CORRUGATED PLATE COALESCER(1)

The horizontal plate coalescer is similar in design to the parallel plate interceptor (Device 2.1.6.20). It consists of packs of plates which are mounted in a horizontal stack about 1/4 inch apart. Laminar flow conditions are established as water flows through the pack. The close spacing of the plates reduces the distance that oil droplets must rise to be collected. The droplets rise vertically a very short distance before they are captured and coalesced with other droplets on the oleophilic plates. These coalesced globules then float to the surface of the separator for removal by skimming or gravity displacement.

Plate-type separators require only one fourth as much space for installation as an API separator with equivalent oil separating efficiency. The compact size makes it easier to provide vapor-tight covers when volatile oils are handled. It also makes a system suitable for shipboard installation. It is possible to upgrade the operation of existing conventional settling basins by installing plate packs. A sediment settling step must be provided ahead of a horizontal plate pack.

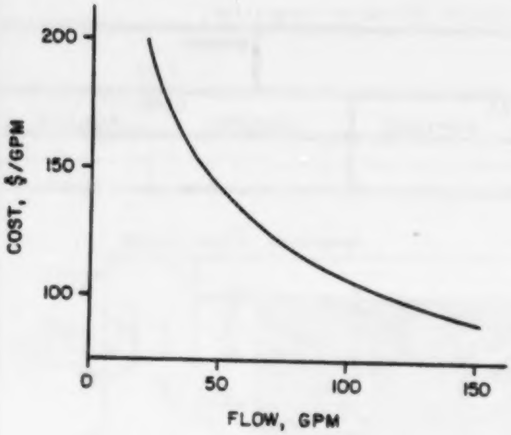
Materials of construction can be varied to withstand corrosive service.

APPLICATION RANGE

Designed for nominal influent concentrations of 4-5% oil, solids up to 200 ppm, detergents to 100 ppm, and oils with specific gravity 0.96 or less. Can be built in modules to handle any flow rate.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	Max 160 °F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS



OPERATING COSTS

The coalescer has no moving parts, therefore very low operating and maintenace costs.

OPERATING EFFICIENCIES

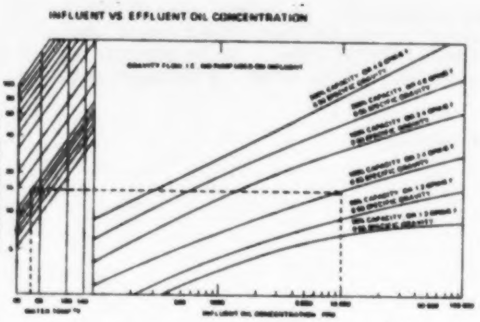


Figure 3. SEPARATION EFFICIENCY(1)

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Re-entry and Environmental Systems Division, General Electric Co.
Facet Enterprises

REFERENCES

1) General Electric Co., Product Bulletin

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Liquid Treatment	Settling, Sedimentation (Oil-Water Separators)

SPECIFIC DEVICE OR PROCESS	NUMBER
Absorbent Drum Separator	2.1.7.13

POLLUTANTS CONTROLLED	AIR		WATER		LAND	
	GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
X ORGANIC				X		
INORGANIC						

	THERMAL
	NOISE

PROCESS DESCRIPTION

The basis of the separator is a rotary drum covered by a thick, reticulated polyurethane foam and an associated squeeze roller. Operations are explained in the seven steps outlined below.

Numbers refer to the illustration in Figure 1.

1. The oil mixture or emulsion enters the inlet section and flows toward the foam formed around the drum.

2. As the foam leaves the squeeze roller, it expands and the opening pores ingest the oily water mixture.

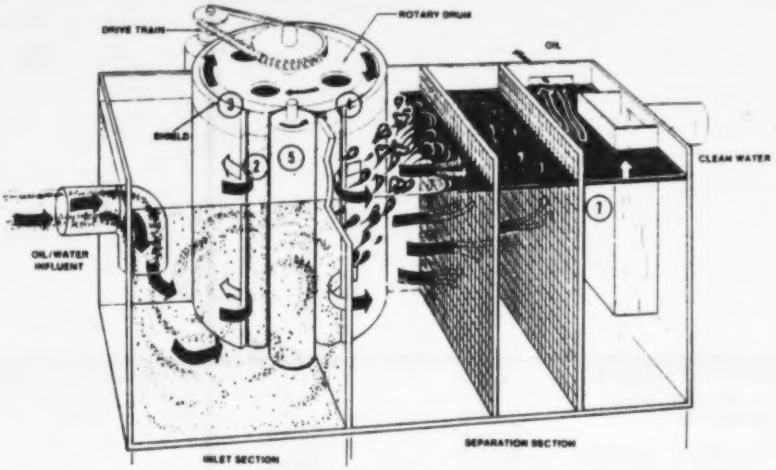


Figure 1. ABSORBENT DRUM OIL/WATER SEPARATOR

3. Each of the tiny foam pores becomes a "quiet" separating chamber. As the drum rotates, each drop of mixture in each pore is held absolutely quiet, permitting oil droplets to rise and to coalesce into an oily film covering the strand surfaces at a rate predictable by Stokes' Law.

4. Separation is completed by the time the drum makes one rotation (about 15 seconds). The clean water is held in the pores and thickened oil is clinging to the strands.

5. The squeeze roller forces the clean water out of the pores, creating a flow force that flushes away solids into the separation section. The roller also forces the now thickened oil from the strands and oil comes off as large drops.

6. In the separation section, the large oil drops rapidly rise to the surface because of their high buoyancy. A diffuser baffle dampens the turbulence caused by the forces at the squeeze roller, providing a smooth flow to enhance separation.

7. Weirs in the outlet section separate the outflow of oil from the top and clean water from the bottom. The inlet section and separation section are sealed from each other by the rotary drum and shield and by the squeeze roller and seal blade. Any effluent must make the circular route in the foam before it can reach the separation and outlet sections. Settled solids are drawn off periodically through two clean-out valves.

APPLICATION RANGE

Standard models handle up to 200 gpm. Larger sizes available. Best performance would be expected with light oils. Cold, viscous oils would not readily diffuse into the pore spaces.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Flow Capacity, GPM	1977 Cost
30	$12,760
70	$15,760
200	$30,030

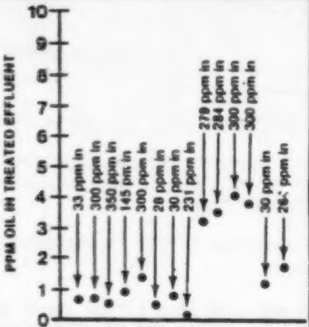
OPERATING COSTS

The only data available for operating costs are the power requirements. Periodic replacement of the absorbent material on the drum could be required. No data available for absorbent life.

Flow Capacity, gpm	Electrical Voltage	Electrical Amps
17.5	115	30
70	230	25
200	230	50

OPERATING EFFICIENCIES

TESTS ON SIMULATED BILGE WATER



Influent oils were a distillate similar to No. 2 fuel oil and a turbine lubrication oil. Each is readily emulsifiable.

Input oil levels ranged from 30 ppm to 350 ppm with oil slugs up to 5%.

Suspended solids ranging in size distribution from 1 to 200 microns were fed along with the oil. There was no plugging at any time.

In tests with storm water runoff from a bulk oil terminal, the average amount of oil in the effluent over a 2.5 month period was 0.97 ppm. Influent levels ranged from 14.6 ppm to 42,000 ppm. There was no plugging at any time and no interference with separating abilities of unit even with industrial detergents and loads of heavy suspended solids such as sand, silt, mosquito larvae and cottonwood lint from a flooding river.

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

MARCO Pollution Control

REFERENCES

1) Product Bulletin, RDS Separator, Marine Construction and Design Co.

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Liquid Treatment	Liquid - Liquid Extraction (Extraction Processes)

SPECIFIC DEVICE OR PROCESS	NUMBER
Jones & Laughlin Dephenolization Process	2.8.1.1

POLLUTANTS CONTROLLED	AIR GASES	AIR PARTICULATES	WATER DISSOLVED	WATER SUSPENDED	LAND LEACHABLE	LAND FUGITIVE
x ORGANIC			x			
INORGANIC						
THERMAL						
NOISE						

PROCESS DESCRIPTION

The Jones & Laughlin process was developed for the recovery of phenols from coke plant aqueous waste. The phenols are recovered from ammonia liquor as free tar acids.

Figure 1 is a flow diagram of the plant. Ammonia liquor is pumped from the ammonia still to the surge tank, which serves to trap some suspended solids and can be by-passed for periodic cleaning. The liquor is then pumped to the top of the extraction column where, as it descends the column, it comes into counter-current contact with the solvent as it rises up through the column. The raffinate is fed to the solvent stripping column where the dissolved solvent is removed from the dephenolized liquor by steam distillation. The solvent stripping column bottoms are then ready for pumping to the sewer line or to a polishing treatment. The overhead product from the solvent stripping column, after condensing, goes to one section of the solvent pumping tank where the water is separated from it and pumped back to the solvent stripping column. The solvent recovered here is ready for recirculation to the extractor. The extract flows from the top of the extractor to the solvent recovery column through a control valve, which maintains a constant interface level between extract and liquor at the top of the extractor. In the solvent recovery column, a separation is made between the solvent and crude tar acids in the extract. The overhead product after condensing goes to the solvent pumping tank, and from there is pumped back to the extractor as recycle solvent with a side stream to the solvent recovery column as reflux. The solvent recovery column bottoms are pumped to the crude tar acids column in which, under vacuum, the solvent content of the crude tar acids is reduced to less than 1 percent. The overhead product is, after condensing, returned to the solvent recovery column with a side stream to the crude tar acids still as reflux.

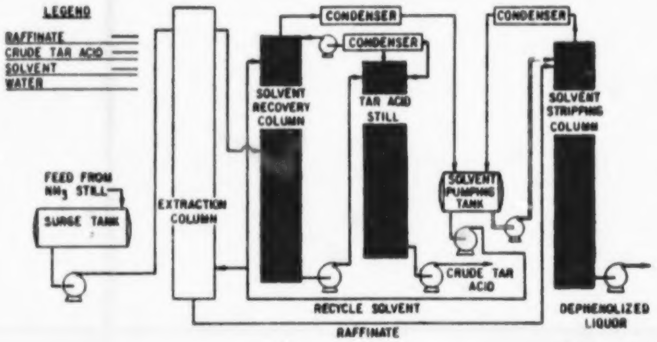


Figure 1. J & L DEPHENOLIZATION PROCESS(1)

APPLICATION RANGE

Extraction processes are indicated when the concentration of phenol and total flow of the aqueous waste is high enough to warrant recovery of phenol as a by-product. This would generally involve phenol concentrations in excess of 500 mg/l.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Installed module cost to treat 330 gpm of phenolic liquor containing 2000 ppm phenol would be approximately $4,000,000 (1977).

Cost includes foundation, piping, electrical, instrumentation, but not storage tanks.

OPERATING COSTS

Utility requirements per 1000 gallon liquor treated:

3.6	kwh
153	lbs of 175 psi steam
281	lbs of 10-20 psi steam
855	gal cooling water (95° max)

Solvent replacement cost:

5¢/1000 gal treated

OPERATING EFFICIENCIES

Based on 1500 ppm phenols in feed:

Phenol removal efficiency = 99%+
Phenol in effluent = 1 to 4 ppm
Soluble tar acids in product = 82%
Solvent in product 1%

ENVIRONMENTAL PROBLEMS

Solvent used is proprietary, so problems caused by traces of solvent in effluent are unknown. Other treatments, such as biological, are required to remove last traces of phenol before discharge.

NOTES

MANUFACTURER / SUPPLIER

Chem-Pro Equipment Corporation

REFERENCES

1) Reprint from Iron & Steel Engineer, May 1969.

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Liquid Treatment	Liquid-Liquid Extraction (Extraction Processes)

SPECIFIC DEVICE OR PROCESS	NUMBER
Phenosolvan Process	2.8.1.2

POLLUTANTS CONTROLLED	AIR		WATER		LAND	
	GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
X ORGANIC			X			
INORGANIC						
THERMAL						
NOISE						

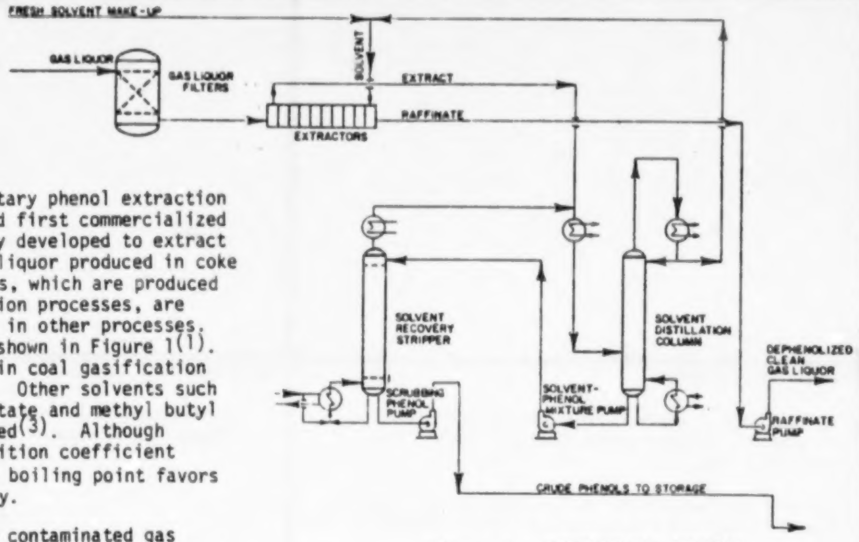

FRESH SOLVENT MAKE-UP
GAS LIQUOR
GAS LIQUOR FILTERS
SOLVENT
EXTRACT
RAFFINATE
EXTRACTORS
SOLVENT RECOVERY STRIPPER
SOLVENT DISTILLATION COLUMN
DEPHENOLIZED CLEAN GAS LIQUOR
SCRUBBING PHENOL PUMP
SOLVENT-PHENOL MIXTURE PUMP
RAFFINATE PUMP
CRUDE PHENOLS TO STORAGE

Figure 1. PHENOSOLVAN PROCESS

PROCESS DESCRIPTION

Phenosolvan is a proprietary phenol extraction process developed by Lurgi and first commercialized about 1940. It was originally developed to extract phenols from the aqueous gas liquor produced in coke oven plants. Dihydric phenols, which are produced in low-temperature carbonization processes, are removed more efficiently than in other processes. A simplified flow diagram is shown in Figure 1(1). The solvent proposed for use in coal gasification plants is isopropyl ether(2). Other solvents such as isobutyl acetate, amyl acetate and methyl butyl ketone have been or can be used(3). Although IPE has a less favorable partition coefficient than butyl acetate, its lower boiling point favors easier separation and recovery.

As seen in Figure 1, the contaminated gas liquor is filtered in a gravel bed type of filter, then passed to the extractor. The extractor is a multi-stage (up to 9 stages) counter-current mixer-settler type. Each stage consists of a smaller mixing tank and a larger separating tank. Submersible pumps serve as mixers.

The extract is distilled in two stages to separate the IPE from the phenol. IPE from the top of the first distillation column is condensed and recycled to the extractor. Additional IPE is added as required for makeup. The bottoms from the first column are steam stripped in a second column to remove the last traces of IPE from the crude phenol. The overhead vapors from the column are condensed and recycled to the first distillation column. Crude phenol is pumped from the bottom of the stripper to storage.

The dephenolized liquor is gas-stripped (not shown) to remove and recover residual solvent.

APPLICATION RANGE

Extraction processes are indicated when the concentration of phenol and total flow of aqueous waste are high enough to warrant recovery of phenols as a by-product. This would generally involve phenol concentrations in excess of 500 mg/l.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	35 °C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

Utility requirements for 1000 gal liquor treated:

90 lbs 150 psi steam
5.3 kwh electricity
2000 gal cooling water

Solvent consumption:

1.2 lb/1000 gal

OPERATING EFFICIENCIES

Extraction efficiency for mono-hydric phenols is 99%+. Overall organic extraction efficiency has been assumed to be 75%(2).

Phenol concentration in the aqueous effluent is estimated to be 10-20 ppm, mainly higher phenols.

ENVIRONMENTAL PROBLEMS

Other treatments such as biological, are required to remove last traces of phenol before discharge.

NOTES

MANUFACTURER / SUPPLIER

Lurgi Mineraloltechnik GmbH

REFERENCES

1) Evaluation of Background Data Relating to New Source Performance Standards for Lurgi Gasification, EPA-600/7-77-057.
2) Beychok, M., "Coal Gasification and the Phenosolvan Process", ACS Division of Fuel Chemistry, V. 19 #5, 1974.
3) Lowry, H., Chemistry of Coal Utilization, Supplementary Volume, Wiley, 1963.

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Liquid-Liquid Extraction (Extraction Processes)
SPECIFIC DEVICE OR PROCESS Phenolics Extraction in Crude Oil Desalters	**NUMBER** 2.8.1.3

POLLUTANTS CONTROLLED	AIR		WATER		LAND	
	GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
X ORGANIC			X			
INORGANIC						
THERMAL						
NOISE						

PROCESS DESCRIPTION

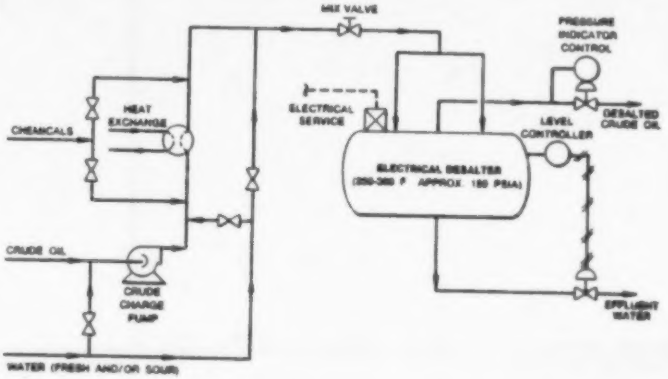

MIX VALVE
PRESSURE INDICATOR CONTROL
ELECTRICAL SERVICE
HEAT EXCHANGE
CHEMICALS
LEVEL CONTROLLER
DESALTED CRUDE OIL
ELECTRICAL DESALTER (250-300 F APPROX. 150 PSIA)
CRUDE OIL
CRUDE CHARGE PUMP
EFFLUENT WATER
WATER (FRESH AND/OR SOUR)

Figure 1. SINGLE STAGE EXTRACTOR-DESALTER(1)

Crude oil desalters are widely used in petroleum refineries to remove inorganic salts from incoming crude oil. The operation consists of a simple water wash to extract the salts, followed by an electrostatic coalescer to separate the oil and water phases. Either single-stage or two-stage units are used. Figure 1 is a flow schematic for a typical single-stage unit.

Wash water requirement for desalting range from 3 to 10% of the crude oil feed rate. Many refineries will use phenolic wastewater as desalter water, thereby simultaneously extracting salt from the crude oil and reducing the phenolic content of the wastewater. The amount of phenolics reduction which can be achieved depends on the aromaticity and phenolics content of the crude oil, the phenolics composition and content of the wastewater, the oil/water ratio, temperature and number of extraction stages.

In Figure 1, the single extraction stage consists of a mixing step, accomplished by the mix valve, and a settling step, accomplished by the desalter.

Some of the phenolics extracted from the phenolic wastewater will reappear in the wastewater stream from the overhead reflux drum of the crude oil distillation column. However, the great majority (90%) of phenolics appears to end up in the heavier distillates, such as kerosene and diesel fuels.

APPLICATION RANGE

Can be used where phenolics in the crude are acceptable to downstream processes. If phenolic wastewater contains ammonia, may lead to foaming problems in desalter.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	140-350 °F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Capital costs will consist only of pumps and piping to accomplish the recycle of wastewater to the desalter.

OPERATING COSTS

As long as problems of foaming, etc. do not arise, the operating cost increment for recycling phenolic waste through the desalter should be negligible. A cost of 0.5 mill per 1000 gallons of oil has been quoted(2).

OPERATING EFFICIENCIES

Although the distribution coefficient for phenolics is relatively low in this system, the high oil/water feed ratio makes it possible to extract as much as 90% of the phenolics from the wastewater. With pH control, the concentration of phenolics in the desalter water effluent may be reduced to as little as 20-30 mg/l.

ENVIRONMENTAL PROBLEMS

Phenolics extracted from wastewater into the crude oil may impart odors to the distillates which are later produced from the crude oil. Desalter water effluent still requires extensive treatment for phenol removal.

NOTES

MANUFACTURER / SUPPLIER

Use of a desalter for phenolics extraction was patented by Metcalf, U.S. Patent 2,785,120, March 12 (1957)

REFERENCES

1) America Petroleum Institute, "Disposal of Refinery Waste Manual - Volume on Liquid Wastes", (1973).
2) Witt, P. A., and Forbes, M. C., "Valuable By-Product Recovery by Solvent Extraction", AIChE Symposium Series, No. 124, Vol. 68, (1972).

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Liquid-Liquid Extraction (Extraction Processes)
SPECIFIC DEVICE OR PROCESS Koppers Light Oil Extraction Process	**NUMBER** 2.8.1.4

POLLUTANTS CONTROLLED	**AIR**				**WATER**				**LAND**			
		GASES		**PARTICULATES**		**DISSOLVED**		**SUSPENDED**		**LEACHABLE**		**FUGITIVE**
x **ORGANIC**					x							
INORGANIC												
THERMAL												
NOISE												

PROCESS DESCRIPTION

Referring to Figure 1, crude ammonia liquor or other aqueous phenolic waste is pumped through filters, cooled to below 40°C, then pumped to the top of a countercurrent liquid extraction tower. The tower internals are Koch Kaskade trays. Liquor passes downward countercurrent to a rising stream of light oil. The extraction oil is a light aromatic solvent with added tar bases to enhance extraction. The oil stream overflows to a decanter where any entrained aqueous phase is removed. From there it passes through two caustic washers where the phenolics are converted to sodium phenolate.

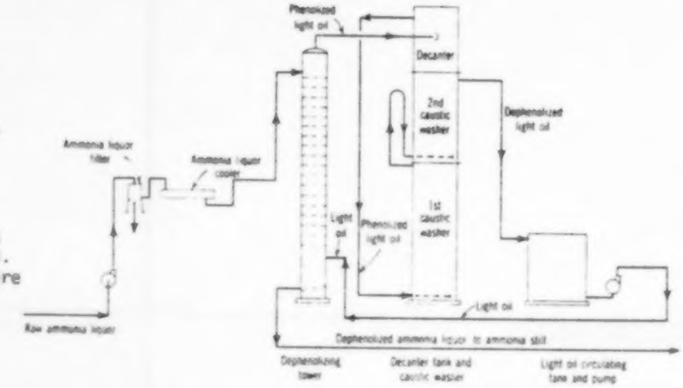

Phenolized light oil
Decanter
2nd caustic washer
Dephenolized light oil
Ammonia liquor filter
Ammonia liquor cooler
Light oil
Phenolized light oil
1st caustic washer
Light oil
Raw ammonia liquor
Dephenolized ammonia liquor to ammonia still
Dephenolizing tower
Decanter tank and caustic washer
Light oil circulating tank and pump

Figure 1. KOPPERS EXTRACTION PROCESS FOR PHENOLS(1)

When concentration of phenolate in the washers reaches a pre-determined level, the contents of the bottom washer are removed and placed by the solution from the upper washer, which is then charged with a fresh solution of sodium hydroxide. Material leaving the bottom washer may be concentrated by evaporation before shipment as a by-product.

APPLICATION RANGE

Extraction processes are indicated when the concentration of phenol and total flow of aqueous waste are high enough to warrant recovery of phenol as a by-product. Concentration must be at least 500 mg/l in most cases. Light-oil extraction is feasible for aqueous wastes from high temperature carbonization of bituminous coal, but not for wastes containing polyhydric phenols.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Costs should be similar to those estimated by Kiezyk & Mackay in 1971(2) for a coke-oven liquor dephenolizing plant. To process 100,000 gal/day containing 5000 ppm phenol would require a capital investment of $400,000.

OPERATING COSTS

From Ref(2), operating cost for 100,000 gal/day is $200,000/yr (1971).

OPERATING EFFICIENCIES

Phenol removal = 99%+.

With an influent concentration of 2000 mg/l, the effluent concentration will be in the range of 10 to 20 mg/l.

ENVIRONMENTAL PROBLEMS

Not effective for removing dihydric phenols. Product is sodium phenolate, which may not have a ready market. Other treatments, such as biological, are rerequired prior to discharge.

NOTES

MANUFACTURER / SUPPLIER

Koppers Co., Inc.

REFERENCES

1) Lowry, H. H., Chemistry of Coal Utilization, Wiley, (1963).
2) Kiezyk, P. R., & Mackay, D., "Wastewater Treatment by Solvent Extraction", Can. & Chem. Engr., Dec. 1971.

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Liquid Treatment	Liquid-Liquid Extraction (Extraction Processes)

SPECIFIC DEVICE OR PROCESS	NUMBER
Chemizon Process	2.8.1.5

POLLUTANTS CONTROLLED		AIR		WATER		LAND	
		GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
x	ORGANIC	☐	☐	☒	☐	☐	☐
☐	INORGANIC	☐	☐	☐	☐	☐	☐
☐	THERMAL						
☐	NOISE						

PROCESS DESCRIPTION

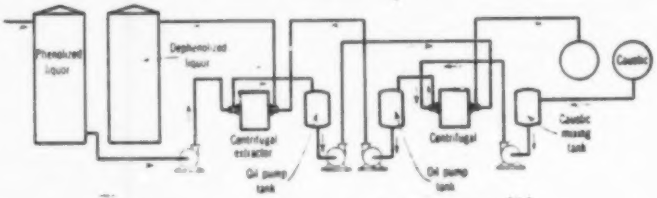


Figure 1. CHEMIZON DEPHENOLIZATION(1)

The Chemizon process utilizes Podbielniak centrifugal extractors in a two-step process for phenol extraction. According to the flow diagram in Figure 1, phenolic ammonia liquor is cooled to 40°C, then pumped to the first centrifugal extractor where it is washed countercurrently with a light oil. In the extractor the heavy (aqueous) phase is introduced at the rotor shaft and is thrown toward the outside, displacing the lighter liquid which then flows inward. The fact that both currents are continuously forced through the holes of the rings arranged concentrically around the axis of the rotor causes an intimate contact of the two phases. The dephenolized aqueous phase, or raffinate, is then sent to a holding tank, while the oil phase, or extract, is sent to a second centrifugal extractor for recovery of phenol by caustic wash. Oil from the first extractor goes first to an oil pump tank. A strong caustic solution is introduced into the suction side of the pump following the oil pump tank. The mixture then flows to the second centrifugal extractor where a more dilute caustic solution is introduced in countercurrent flow. The two phenolate solutions mix at the periphery of the rotor.

Extracted oil from the second centrifugal then returns to the first stage to contact more phenolic waste. The caustic solution of sodium phenolate is marketed directly as a by-product of the process.

APPLICATION RANGE

Extraction processes are indicated when the concentration of phenol and total flow of aqueous waste are high enough to warrant recovery of phenol as a by-product. This would generally involve phenol concentrations in excess of 500 mg/l. Light oils are not effective solvents for polyhydric phenols.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	40 °C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Cost for a single centrifugal extractor (equipment cost only; installation not included) to handle 500-600 gpm total flow (aqueous waste + solvent oil, combined flow) in 316 S.S construction is approximately $210,000 (1978).

Installed cost to treat 200,000 gpd is given as $2.50 - $3.00 per daily gallon, cost year not given(2).

OPERATING COSTS

Sodium hydroxide usage is approximately one pound per pound of phenol extracted.

OPERATING EFFICIENCIES

Phenol extraction efficiency is 99%+.

With an influent phenol concentration of 2500 to 3000 mg/l, the effluent concentration is on the order of 25 mg/l.

ENVIRONMENTAL PROBLEMS

Not effective for removing dihydric phenols. Sodium phenolate product may not have a ready market. Additional treatment for phenol removal required prior to discharge.

NOTES

MANUFACTURER / SUPPLIER

Extractor - Baker Perkins, Inc.

REFERENCES

1) Lowry, H. H., Chemistry of Coal Utilization, Wiley (1963).
2) Besselievre, E. B., The Treatment of Industrial Wastes, McGraw-Hill (1969).

CLASSIFICATION
Liquid Treatment

GENERIC DEVICE OR PROCESS
Liquid-Liquid Extraction (Extraction Processes)

SPECIFIC DEVICE OR PROCESS
Barrett Phenol Recovery Process

NUMBER
2.8.1.6

POLLUTANTS CONTROLLED		AIR		WATER		LAND	
		GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
X	ORGANIC			X			
	INORGANIC						
	THERMAL						
	NOISE						

PROCESS DESCRIPTION

Wastes are collected in a storage tank, and pumped at a controlled rate to the base of a rotating disc contactor (RDC). The waste rises through the extractor as the continuous phase. It is contacted by a falling dispersed stream of solvent. Dephenolized waste exits the RDC after passing through a short settling zone to minimize solvent loss by entrainment. The waste then goes to a batch discharge tank for monitored flow to the plant sewer system.

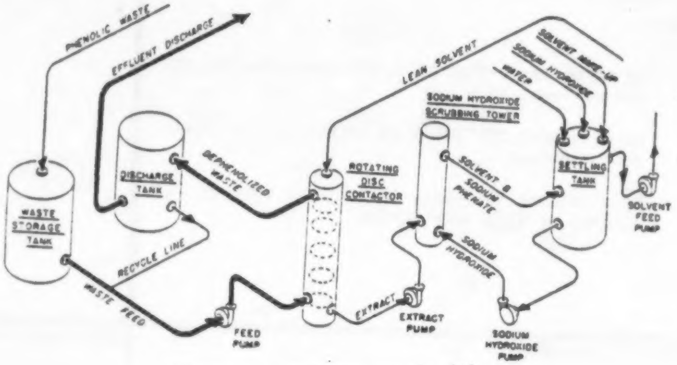

PHENOLIC WASTE
EFFLUENT DISCHARGE
LEAN SOLVENT
SOLVENT MAKE-UP
SODIUM HYDROXIDE
WATER
SODIUM HYDROXIDE SCRUBBING TOWER
DISCHARGE TANK
DEPHENOLIZED WASTE
ROTATING DISC CONTACTOR
SOLVENT & SODIUM PHENATE
SETTLING TANK
SOLVENT FEED PUMP
WASTE STORAGE TANK
RECYCLE LINE
SODIUM HYDROXIDE
WASTE FEED
EXTRACT
FEED PUMP
EXTRACT PUMP
SODIUM HYDROXIDE PUMP

Figure 1. BARRETT PROCESS(1)

The phenolized solvent or extract passes through a disengaging section at the base of the RDC to minimize waste entrainment and is pumped to the base of a concurrent liquid-liquid caustic spray tower. Solvent flow from the RDC is controlled automatically by a level indicator at its base. Rich solvent entering the spray tower is dispersed into a continuous phase of sodium hydroxide sodium phenolate mixture. The phenolics contributed by the extract react with the sodium hydroxide to form more sodium phenolate. Lean solvent and caustic soda phenolate mixture then leave the top of the spray tower and flow to a settling and storage tank prior to recycle.

Satisfactory dephenolizer performance has been obtained using a phenolate saturated to as high as 90-95 percent. When this saturation level is reached the solvent regeneration unit is charged with fresh 20 to 35 weight percent caustic soda and saturated phenolate is then shipped out for recovery of phenolic values.

APPLICATION RANGE

Extraction processes are indicated when the concentration of phenol and total flow of aqueous waste are high enough to warrent recovery of phenol as a by-product.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	60-90 °F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

1957 estimates(1)

Waste Volume Gallons Per Day	Annual Return	Capital Cost	Payout Time, Years
100,000	$ 40,000	$200,000	4
170,000	70,000	260,000	3
500,000	200,000	670,000	2.9

Note:

[1] Based on waste feed of 5,000 ppm phenolics and and effluent of 5 ppm.

[2] No allowance for plant administration or overhead expenses.

[3] No allowance for waste collection, storage, cleanup or site development.

OPERATING COSTS

OPERATING EFFICIENCIES

PERFORMANCE TEST DATA

Flow Rate, GPM		Solvent to Waste Ratio	Phenolic Conc., PPM		Rotor Speed RPM
Solvent	Waste		Feed	Effluent	
8	8	1	5,800	9	55
12	6	2	5,400	3	55
12	4	3	5,400	1.6	55

EFFECT OF WASTE pH ON DEPHENOLIZATION EFFICIENCY

Flow Rate, GPM		Water Feed pH	Phenolic Conc., PPM		Dephenolization Efficiency
Solvent	Waste		Waste	Effluent	
8	8	9.1	5,300	90	98.3
8	8	7.9	4,500	16	99.7
8	8	7.4	5,800	9	99.8

ENVIRONMENTAL PROBLEMS

Sodium hydroxide - sodium phenolate product may not have a ready market. Additional treatment of waste stream for phenol removal required prior to discharge.

NOTES

MANUFACTURER / SUPPLIER

REFERENCES

1. Heller, A. N., Clarke, E. W., Reiter, W. M., "Some Factors in the Selection of a Phenol Recovery Process", Proceedings of 12th Purdue Industrial Waste Conference, (1957).

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Liquid-Liquid Extraction (Extraction Processes)
SPECIFIC DEVICE OR PROCESS Phenex Process	**NUMBER** 2.8.1.7

POLLUTANTS CONTROLLED	**AIR** GASES	**AIR** PARTICULATES	**WATER** DISSOLVED	**WATER** SUSPENDED	**LAND** LEACHABLE	**LAND** FUGITIVE
X ORGANIC	☐	☐	X	☐	☐	☐
☐ INORGANIC	☐	☐	☐	☐	☐	☐
☐ THERMAL						
☐ NOISE						

PROCESS DESCRIPTION

The Phenex process was developed to extract phenolics from refinery wastewaters by using an aromatic light oil (catalytic cracking cycle oil, or light cycle oil, LCO) as the extraction solvent. After extracting phenolics from the wastewater stream, the cycle oil itself is treated with caustic to remove the phenolics. The phenolic-lean cycle oil can then be re-used as the extraction solvent.

Electrostatic coalescers are utilized to provide separation of the oil and water phases in the wastewater extraction stage and to provide separation of the oil and caustic phases in the cycle oil phenolics removal stage. A flow diagram of the process is shown in Figure 1. Phenolic wastewater and light cycle oil are fed through a butterfly mixing valve and then to an electrostatic coalescing drum. Although Figure 1 illustrates a single-stage extraction, more stages could be used if economically justified. Overall phenolics extraction of 60 to 80% in a single-stage process would be upgraded to 90-95% with a two-stage system.

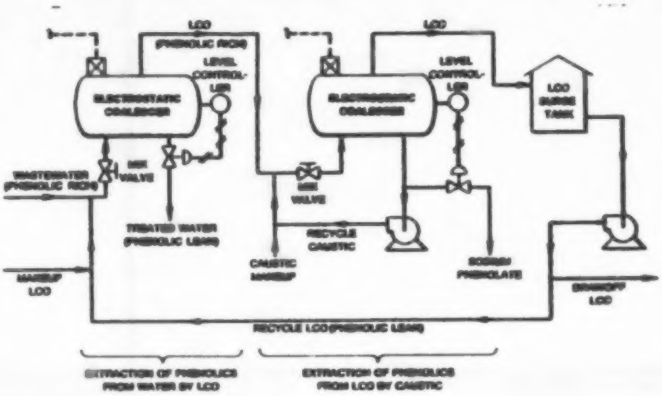

LCO
(PHENOLIC RICH)
LEVEL CONTROLLER
ELECTROSTATIC COALESCER
WASTEWATER (PHENOLIC RICH)
MIX VALVE
TREATED WATER (PHENOLIC LEAN)
MAKEUP LCO
LCO
LEVEL CONTROLLER
ELECTROSTATIC COALESCER
LCO SURGE TANK
MIX VALVE
RECYCLE CAUSTIC
CAUSTIC MAKEUP
SODIUM PHENOLATE
DRAWOFF LCO
RECYCLE LCO (PHENOLIC LEAN)
EXTRACTION OF PHENOLICS FROM WATER BY LCO
EXTRACTION OF PHENOLICS FROM LCO BY CAUSTIC

Figure 1. PHENEX PROCESS(2)

Mixing valve energy is adjusted to provide good two-phase contact, but not enough to create a difficult-to-treat emulsion. Cycle oil flowing from the top of the coalescer is mixed with caustic and then separated in a second electrostatic coalescer. In some cases the caustic treatment may not be necessary. The phenols extracted are oxidation inhibitors and serve to improve color stability and reduce sediment formation during oil storage. This may be beneficial when catalytic cycle oil is blended into distillate fuels. Aromatic solvents other than light cycle oil can be used.

APPLICATION RANGE

Extraction processes are indicated when the concentration of phenol and total flow of aqueous waste are high enough to warrant recovery of phenol as a by-product. This would generally involve phenol concentrations in excess of 500 mg/l.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Installed cost for a refinery in 1966 was given as \$200,000(1). Flow rates were not specified.

OPERATING COSTS

Power consumption, solvent loss, and operating manpower requirements are stated to be minimal.

OPERATING EFFICIENCIES

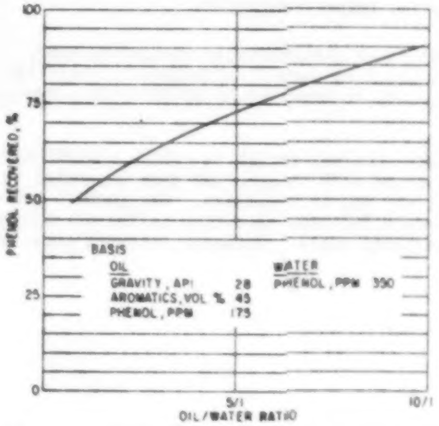


Figure 2. REMOVAL EFFICIENCY AS A FUNCTION OF OIL/WATER RATIO(1)

Efficiency shown is for a single-stage process.

ENVIRONMENTAL PROBLEMS

Additional treatment for phenol removal required prior to discharge.

NOTES

MANUFACTURER/SUPPLIER

Howe-Baker Engineers, Inc.

REFERENCES

1) Lewis, W. L., Martin, W. L., "Removal Phenols from Wastewater", Hydrocarbon Processing, February 1967.
2) American Petroleum Institute, "Disposal of Refinery Wastes Manual-Volume of Liquid Wastes", (1973).

CLASSIFICATION Liquid Treatment	**GENERIC DEVICE OR PROCESS** Liquid-Liquid Extraction (Differential Contact Gravity Columns)
SPECIFIC DEVICE OR PROCESS Pall Rings	**NUMBER** 2.8.3.8

	POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
		GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
x	**ORGANIC**			x			
x	**INORGANIC**			x			
	THERMAL						
	NOISE						

PROCESS DESCRIPTION

The use of a packing material in a liquid-liquid extraction column will usually increase the extraction efficiency. Almost any type of packing used in distillation or absorption can also be used in extraction. Pall rings, with their large void volume, are efficient because they do not retard the flow of the continuous phase appreciably, but yet inhibit harmful axial mixing. Pall rings were developed as an improvement over Rashig rings. Higher velocities and column throughputs can be maintained. The packing material should normally be chosen so that the continuous phase wets the packing, thus insuring that dispersed phase droplets do not coalesce or form films on the surface. Size of the packing should be such that the openings are not so small as to retard the flow of dispersed phase droplets. Standard sizes for Pall rings are 5/8, 1, 1-1/2, 2 and 3 inches. The exterior dimensions of a Pall ring are the same as a Raschig ring, a cylinder of length equal to diameter. Many materials of construction are available, including most steels, copper, aluminum and many plastics.

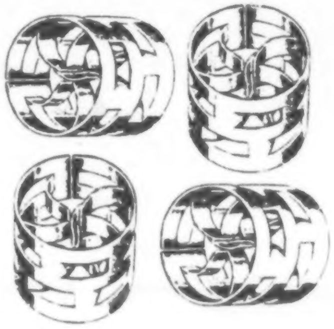


Figure 1. METAL PALL RINGS.

APPLICATION RANGE

When used in liquid-liquid extraction, at least an 8:1 tower diameter to packing size should be employed to insure against inefficiency due to channeling. Materials should be chosen such that the continuous liquid phase preferentially wets the packing.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Dollars per cubic foot, 1978.

Size, Inches	Carbon Steel	316 Stainless Steel	Polypropylene
1	20	85	16
1-1/2	16	60	10
2	14	53	9

OPERATING COSTS

OPERATING EFFICIENCIES

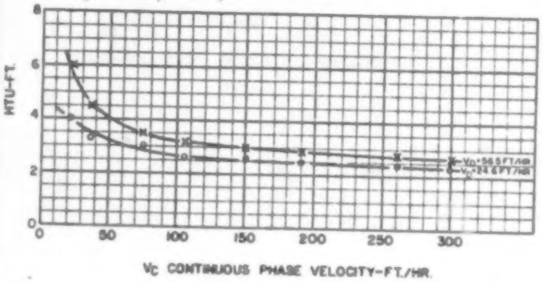


Figure 2. EXTRACTION EFFICIENCY OF PALL RINGS[1].

Efficiency given as Height Equivalent to a Transfer Unit for 1-inch copper pall rings in a 5-foot high column extracting MEK-water-kerosene.

ENVIRONMENTAL PROBLEMS

NOTES

MANUFACTURER / SUPPLIER

Chemical Process Products Division, Norton Co.
Glitsch, Inc.

REFERENCES

1. Nemunatis, R. R., Eckert, J. S., Foote, E. H., Rollison, L. R., "Packed Liquid-Liquid Extractors", Chemical Engineering Progress, Vol. 67, No. 11, November 1971, p. 60.

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Pond Lining (Membrane Linings)
SPECIFIC DEVICE OR PROCESS Butyl Rubber	**NUMBER** 4.1.1.1

POLLUTANTS CONTROLLED	**AIR** GASES	**AIR** PARTICULATES	**WATER** DISSOLVED	**WATER** SUSPENDED	**LAND** LEACHABLE	**LAND** FUGITIVE
x **ORGANIC**			x		x	
x **INORGANIC**			x		x	
THERMAL						
NOISE						

PROCESS DESCRIPTION

Butyl rubber is a nonpolar copolymer of isobutylene (97%) and isoprene. The vulcanized compound can be used as a pond liner and is available in either unsupported or fabric-reinforced sheeting of 20 to 125 mil thickness. It has questionable resistance to ozone and ultraviolet light. Consequently, in some cases, it may require an earth cover. Figure 1 shows a schematic diagram of a lined disposal pond which can be used to store wastewater prior to treatment, disposal, or reuse. In addition, the pond can be used to evaporate the volatile portion of an effluent and to contain any precipitated or settled solids.

Similar to other membrane liners, butyl sheeting is usually made in a continuous process where a thin sheet is formed by passing the compound through the rolls of a calender. Butyl can also be reinforced with a fabric (scrim) laminated between two layers. Nylon, dacron, polypropylene, or fiberglass can be used for this purpose. Reinforced liners provide better dimensional stability, better puncture resistance and greater hydrostatic load capacities. However, they also result in less elongation prior to rupture, less conformity to ground irregularities, less flexibility, and greater cost. The tensile strength for butyl rubber can range from 1000 to 4000 psi[A]. The membrane liner is manufactured as a roll-good and fabricated into panels before installation. Additional material must be provided to allow for shrinkage, typically 15%.

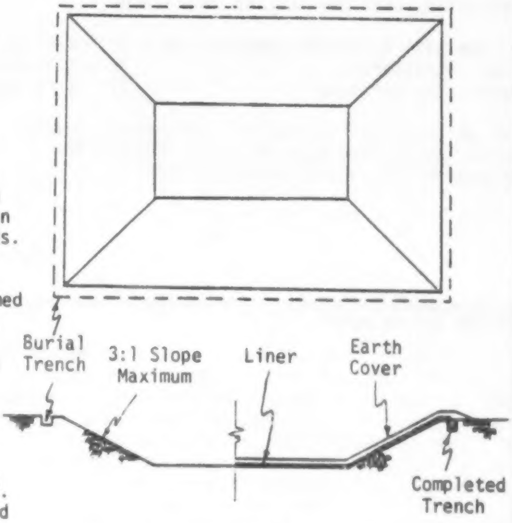


Figure 1. MEMBRANE LINED DISPOSAL POND

Butyl rubber is installed in a manner similar to all other membrane liners. The pond is formed and smoothed by conventional methods, and a trench is dug around the perimeter (see Figure 1 left side). The liner is installed and buried in the trench for stability. Butyl rubber is the most difficult membrane liner to field splice. It requires a special two-part cold curing adhesive with a cap strip, and must be done under dry conditions. A second method used today is a tongue and groove system with a gum tap adhesive. Seams to foreign surfaces like concrete, must be backed up with a mechanical anchor system. In general, the pond bottom should be slightly sloped (2%) to allow any entrapped air to escape after filling.

In some cases, it is extremely important to detect a leak as soon after it is formed as possible. A secondary liner can be provided for this purpose. Leaks if they occur are collected in the secondary liner and drawn off by a separate piping system. Other methods to detect leaks include groundwater monitoring wells, and electrical sensing systems. In some cases they may increase the cost of the pond by as much as two fold.

Butyl rubber can be used in lined burial pits (device 4.3.2.4) but the liner should be buried with an earth cover of 1 to 2 ft to prevent liner damage. Earth covers can also be used in ponds to prevent physical damage or vandalism. In addition, they may be used when a natural bottom is required such as in fish culture and in esthetic landscaping.

APPLICATION RANGE

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE Max	90 °C	200 °F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

Butyl rubber is resistant to water based inorganic salts, acids, bases, sewage, oxidizing chemicals, animal and vegetable oils, and fats. The rubber compound itself generally contains low amounts of extractable material and does not swell in water. However, it is not recommended for service requiring contact with hydrocarbons, petroleum solvents, and aromatic and halogenated solvents. Butyl rubber, in general, ages very well, but some butyl compounds ozone crack. Some recent compounds contain minor amounts of EPDM[D] to improve ozone resistance.

The above information should be used as a guide and not for design purposes. A sample should be tested in actual service before a liner material is specified.

CAPITAL COSTS

The capital costs for butyl rubber membrane liners are shown below[C]. The costs are January, 1978 costs, and are for material only with no cost break for large quantities. Costs are shown as $/sq ft.

Thickness	Reinforced	Cost
30 mil	no	0.44
60 mil	no	0.64
60 mil	yes	0.77

Installation costs can vary as shown below[1].

Cut and Fill Reservoir Construction	$.02 - $.05/gal
Liner Installation	$.02 - $.06/sq ft
Earth Cover (6" deep)	$.01 - $.04/sq ft

The above costs can vary greatly depending upon the location, design and type of liner. Contact the manufacturer for detailed cost information.

OPERATING COSTS

Operating costs include maintenance of the earth cover (if included), monitoring leak detection equipment, and repairing leaks. The maintenance of the earth cover is site specific, and is dependent upon weather conditions and pond design. If a leak is detected, the pond can be drained to expose the liner for repairs. Care must be taken to insure that a clear, dry area is provided for the splice.

OPERATING EFFICIENCIES

Lined disposal ponds are an effective method for disposal of liquid effluents. The actual operating efficiency for butyl rubber is impossible to estimate. The major source of emissions are poor splicing and cracks from chemicals that are not compatible with the butyl rubber. The permeability for butyl rubber is the best of all membrane liners; typically it is 0.15 perm-mils[A]. In most cases, however, a permeability of essentially zero can be realized. In water management use, butyl rubber liners have shown no degredation after 20 years of exposed service.

ENVIRONMENTAL PROBLEMS

Disposal of liquid waste in a lined disposal pond is effective in containing the major portion of the effluent. However, fugitive emissions may be produced from the following two areas:

1) Leaks may develop around seams or at locations where the liner is attacked by the chemicals contained in the liquid waste.

2) Volatile pollutants may be released from the waste liquid as the water is evaporated.

NOTES

A) Source: "Selecting and Installing Synthetic Pond Linings", Chemical Eng. Vol 80, No. 3, 2/5/73.

B) Operating temperatures ranges from -50 to 200°F[1] but some report operating temperature up to 325°F[A].

C) Capital costs are estimated from manufacturer's data.

D) See device sheet 4.1.1.2.

MANUFACTURER / SUPPLIER

Aldan Rubber Co.
Brown & Browh, Inc.
Carlisle Tire & Rubber Co.
Cooley, Inc.
Dearborn Canvas Products Co.
Eastern Gunite Co.
Globe Linings, Inc.
Gulf Seal Corp.
Key Enterprises
McKitrick Mudd
Miner Co., Ltd., The
Misco-United Supply, Inc.
Pacific Lining Co., Inc.
Plymouth Rubber Co.
Reeves Brothers, Inc.
Richardson Co.,
Staflex
U.S. Rubber Co.
Watersaver Co.

REFERENCES

1) Kays, William B., Construction of Linings for Reservoirs, Tanks, and Pollution Control Facilities, John Wiley & Sons, New York, N.Y., (1977).
2) Geswein, Allen J., "Liners for Land Disposal Sites - An Assessment", EPA/530/SW-137, (March 1975).
3) Haxo, Henry E., Jr., Haxo, Robert S., White, Richard M., "Liner Materials Exposed to Hazardous and Toxic Sludges, First Interim Report", EPA 600/2-77-081 (June 1977).

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Pond Lining (Membrane Linings)
SPECIFIC DEVICE OR PROCESS Ethylene Propylene Diene Monomer (EPDM)	**NUMBER** 4.1.1.2

POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
	GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
☐ **ORGANIC**	☐	☐	☐	☐	☐	☐
☒ **INORGANIC**	☐	☐	☒	☐	☒	☐
☐ **THERMAL**						
☐ **NOISE**						

PROCESS DESCRIPTION

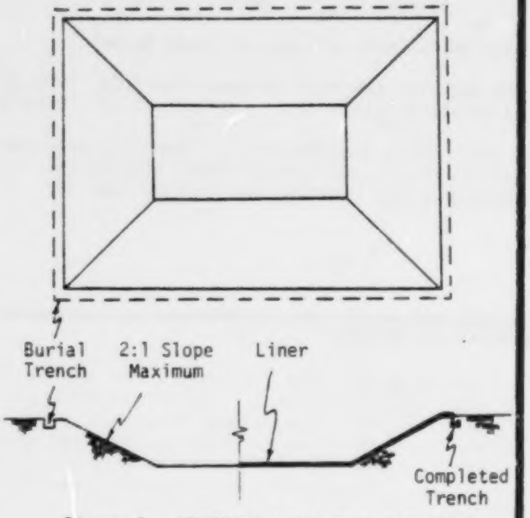


Figure 1. MEMBRANE LINED DISPOSAL POND

Ethylene, propylene, diene monomer (EPDM) is a synthetic rubber originally developed by the U.S. Rubber Co. A similar compound, elhylene, propylene terpolymer (EPT[A]), was developed by DuPont and is a terpolymer of ethylene, propylene and an unidentified chemical referred to as a noncojugated diene. Neither company would divulge the exact nature of the unnamed monomer. EPDM is a wholly hydrocarbon, vulcanized rubber and is available in thicknesses from 20 to 125 mils. It is usually blended with butyl (4.1.1.1). It has excellent resistance to weather conditions[B], and can be used without an earthen cover as shown in Figure 1. This pond can be used to store wastewater prior to treatment, disposal, or reuse; to evaporate the volatile portion of an effluent; and to contain any precipitated or settled solids.

Similar to other membrane liners, EPDM sheeting is usually made in a continuous process where a thin sheet is formed by passing the compound through the rolls of a calender. EPDM can be reinforced with a fabric (scrim) laminated between two layers. Nylon, dacron, polypropylene, or fiberglass can be used for this purpose. Reinforced liners provide better dimensional stability, better puncture resistance and greater hydrostatic load capacities. However, they also result in less elongation prior to rupture, less conformity to ground irregularities, less flexibility, and greater cost. The tensile strength for EPDM is specified as 1400 psi[C]. The membrane liner is manufactured as a roll-good and fabricated into panels before installation. Additional material must be provided for unsupported EPDM to allow for shrinkage, 5% maximum.

EPDM is installed in a manner similar to all other membrane liners. The pond is formed and smoothed by conventional methods, and a trench is dug around the perimeter (see Figure 1 left side). The liner is installed and buried in the trench for stability. Field seams are made using a one-step vulcanizable adhesive with a cap strip. Gum tape is often required in the installation which may increase the costs. In general, the pond bottom should be slightly sloped (2%) to allow any entrapped air to escape after filling.

In some cases, it is extremely important to detect a leak immediately after it is formed. A secondary liner can be provided for this purpose. Leaks if they occur are collected in the secondary liner and drawn off by a separate piping system. Other methods to detect leaks include groundwater monitoring wells, and electrical sensing systems. In some cases this may increase the cost of the pond by as much as two fold.

EPDM can be used in lined burial pits (device 4.3.2.4) but the liner should be buried with an earth cover of 1 to 2 ft to prevent liner damage. Earth covers can also be used in ponds to prevent physical damage or vandalism. In addition, they may be used when a natural bottom is required such as in fish culture and in esthetic landscaping.

APPLICATION RANGE

EPDM was originally developed for contact with potable water, but has excellent resistance to moderate acids, bases, and salt solutions. In most cases, it is resistant to ketons, esters and alcohols. EPDM is not recommended for applications involving hydrocarbons, petroleum solvents, or aromatic solvents. It has good weatherability, low temperature flexibilities, and good heat resistance.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE Max	150 °C	300°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

Compounding has a great deal to do with the applicability of a specific EPDM liner. In general, they can be expected to last from 15 to 25 years under normal use, but tests should be conducted under actual service conditions before a liner material is specified.

CAPITAL COSTS

The capital costs for EPDM liners are shown below[D]. The costs are January, 1978 costs, and are for material only with no cost break for large quantities. Costs are shown as $/sq/ft.

Thickness	Reinforced	Cost
30 mil	no	0.44
60 mil	no	0.64
60 mil	yes	0.77

Installation costs can vary as shown below[1].

Cut and Fill Reservoir Construction	$.02 - $.05/gal
Liner Installation	$.02 - $.06/sq ft

The above costs can vary greatly depending upon the location, design and type of liner. Contact the manufacturer for detailed cost information.

OPERATING COSTS

Operating costs include maintenance of the earth cover (if included), monitoring leak detection equipment, and repairing leaks. The maintenance of the earth cover is site specific, and is dependent upon weather conditions and pond design. If a leak is detected, the pond can be drained to expose the liner for repairs. Care must be taken to insure that a clean, dry area is provided for the splice.

OPERATING EFFICIENCIES

Lined disposal ponds are an effective method for disposal of liquid effluents. The actual operating efficiency for EPDM is impossible to estimate. The major source of emissions are poor splicing and cracks from chemicals that are not compatable with the EPDM. In most cases a permeability of essentially zero can be realized.

ENVIRONMENTAL PROBLEMS

Disposal of liquid waste in a lined disposal pond is effective in containing the major portion of the effluent. However, fugitive emissions may be produced from the following two areas:

1) Leaks may develop around seams or at locations where the liner is attacked by the chemicals contained in the liquid waste.

2) Volatile pollutants may be released from the waste liquid as the water is evaporated.

NOTES

A) Trade named Nordel. Both compounds are referred to as EPDM in this data sheet.

B) Operating temperature range is -65°F to 300°F.

C) ASTM D-412-68.

D) Capital costs are estimated from manufacturer's data.

MANUFACTURER / SUPPLIER

B. F. Goodrich Co.
Burke Rubber Co.
Carlisle Tire & Rubber Co.
Cooley, Inc.
Crestline
Dearborn Canvas Products Co.
Eastern Gunite Co.
E.I. duPont de Nemours Co., Inc.
Globe Linings, Inc.
Gulf Seal Corp.
Key Enterprises
McKitrick Mudd
Miner Co., Ltd., The
Misco-United Supply, Inc.
Pacific Lining Co., Inc.
Plymouth Rubber Co.
Reeves Brothers, Inc.
Staflex
Watersaver Co.

REFERENCES

1) Kays, William B., Construction of Linings for Reservoirs, Tanks, and Pollution Control Facilities, John Wiley & Sons, New York, N.Y., (1977).
2) Geswein, Allen J., "Liners for Land Disposal Sites - An Assessment", EPA/530/SW-137, (March 1975).
3) Haxo, Henry E., Jr., Haxo, Robert S. White, Richard M., "Liner Materials Exposed to Hazardous and Toxic Sludges, First Interim Report", EPA 600/2-77-081 (June 1977).

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Pond Lining (Membrane Linings)
SPECIFIC DEVICE OR PROCESS Neoprene	**NUMBER** 4.1.1.3

POLLUTANTS CONTROLLED		**AIR**		**WATER**		**LAND**	
		GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
x	**ORGANIC**			x	x	x	
x	**INORGANIC**			x	x	x	
	THERMAL						
	NOISE						

PROCESS DESCRIPTION

Neoprene is a synthetic rubber produced by a controlled polymerization of chloropene, a compound similar to isoprene with a chlorine atom replacing a methyl group. It is supplied in vulcanized sheets from 30 to 125 mil thickness. Neoprene has excellent weatherability[A] and can be used without an earth cover as shown in Figure 1. This figure shows the construction details for a lined disposal pond which can be used to store wastewater prior to treatment, disposal, or reuse. In addition, the pond can be used to evaporate the volatile portion of an effluent and to contain any precipitated or settled solids.

Similar to other membrane liners, neoprene sheeting is usually made in a continuous process where a thin sheet is formed by passing the compound through the rolls of a calender. Neoprene can also be reinforced with a fabric (scrim) laminated between two layers. Nylon, dacron, polypropylene, or fiberglass can be used for this purpose. Reinforced liners provide better dimensional stability, better puncture resistance and greater hydrostatic load capacities. However, they also result in less elongation prior to rupture, less conformity to ground irregularities, less flexibility, and greater cost. Neoprene is extremely resistant to puncturing, abrasion, and mechanical damage. The tensile strength has been specified at 1500 psi minimum[B]. The membrane liner is manufactured as a roll-good and fabricated into panels before installation.

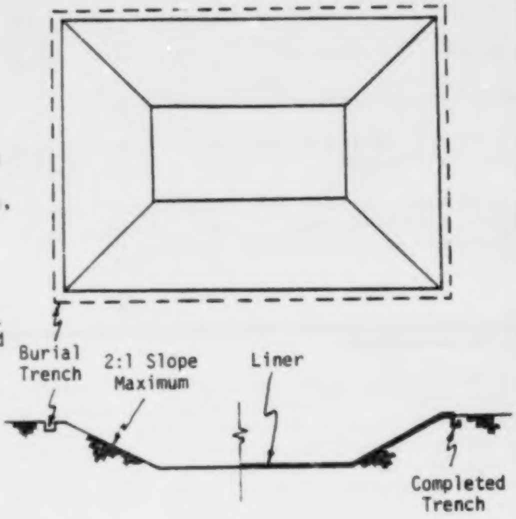


Figure 1. MEMBRANE LINED DISPOSAL POND

Neoprene is installed in a manner similar to all other membrane liners. The pond is formed and smoothed by conventional methods, and a trench is dug around the perimeter (see Figure 1 left side). The liner is installed and buried in the trench for stability. In general, the pond bottom should be slightly sloped (2%) to allow[C] any entrapped air to escape after filling. Field seams are easy to make with vulcanizing cements and adhesives but their long term integrity in contact with petroleum oils may be questionable. Neoprene has poor seam strength in these applications. In addition, the bonding of neoprene to foreign surfaces can only be termed as fair.

In some cases, it is extremely important to detect a leak immediately after it is formed. A secondary liner can be provided for this purpose. Leaks if they occur are collected in the secondary liner and drawn off by a separate piping system. Other methods to detect leaks include groundwater monitoring wells, and electrical sensing systems. In some cases they may increase the cost of the pond by as much as two fold.

Neoprene can be fabricated into an embankment supported Fabritank[F]. The Fabritank is made entirely of neoprene and resembles a pillowcase, seamed on all four sides. This system provides an integral cover and can be used to eliminate evaporation emissions. Neoprene can also be used in lined burial pits (device 4.3.2.4) but the liner should be buried with an earth cover of 1 to 2 ft to prevent liner damage. Earth covers can also be used in ponds to prevent physical damage or vandalism. In addition, they may be used when a natural bottom is required such as in fish culture and in esthetic landscaping.

APPLICATION RANGE

Neoprene has good resistance to bases, moderate acids, ozone, oils, fats, greases, and many hydrocarbon oils and solvents. It is not resistant to strong oxidizing acids, acetic acid, ketones, esters, chlorinated and nitro-hydrocarbons, and aromatic solvents. It has good flame resistance, but sun aging may be a problem with the thinner materials[D].

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE Max	90 °C	200 °F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

The above information should be used as a guide and not for design purposes. A sample should be tested in actual service before a liner material is specified.

CAPITAL COSTS

The capital costs for Neoprene membrane liners are shown below[E]. The costs are January, 1978 costs, and are for material only with no cost break for large quantities. Costs are shown as $/sq ft.

Thickness	Weight	Reinforced	Cost
--	16 oz/yd^2	yes	0.52
60 mil	--	yes	1.10
30 mil	--	no	0.64
60 mil	--	no	0.95

Installation costs can vary as shown below[1].

Cut and Fill Reservoir Construction	$.02 - $.05/gal
Liner Installation	$.02 - $.06/sq yd

The above costs can vary greatly depending upon the location, design and type of liner. Contact the manufacturer for detailed cost information.

OPERATING COSTS

Operating costs include maintenance of the earth cover (if included), monitoring leak detection equipment, and repairing leaks. The maintenance of the earth cover is site specific, and is dependent upon weather conditions and pond design. If a leak is detected, the pond can be drained to expose the liner for repairs. Care must be taken to insure that a clean, dry area is provided for the splice.

OPERATING EFFICIENCIES

Lined disposal ponds are an effective method for disposal of liquid effluents. The actual operating efficiency for Neoprene is impossible to estimate. The major source of emissions are poor splicing and cracks from chemicals that are not compatible with the liner. In most cases a permeability of essentially zero can be realized.

ENVIRONMENTAL PROBLEMS

Disposal of liquid waste in a lined disposal pond is effective in containing the major portion of the effluent. However, fugitive emissions may be produced from the following two areas:

1) Leaks may develop around seams or at locations where the liner is attacked by the chemicals contained in the liquid waste.

2) Volatile pollutants may be released from the waste liquid as the water is evaporated.

NOTES

A) Operating temperature ranges from -40° to 200°F, with intermittent temperatures up to 250°F.

B) ASTM D-412-68.

C) Neoprene cannot be seamed in cold or wet weather.

D) Estimated life for 20 mil material would be 8 years.

E) Capital costs are estimated from manufacturer's data.

F) Fabritank is a registered trademark of Firestone.

MANUFACTURER/SUPPLIER

Brown & Brown, Inc.
Carlisle Tire and Rubber Co.
Cooley, Inc.
Crestline
Dearborn Canvas Products Co.
Eastern Gunite Co.
Firestone Coated Fabrics Co.
Globe Linings, Inc.
Gulf Seal Corp.
Misco-United Supply, Inc.
Pacific Lining Co., Inc.
Plymouth Rubber Co.
Reeves Brothers, Inc.
Staflex
Watersaver Co.

REFERENCES

1) Kays, William B., Construction of Linings for Reservoirs, Tanks, and Pollution Control Facilities, John Wiley & Sons, New York, N.Y., (1977).
2) Geswein, Allen J., "Liners for Land Disposal Sites - An Assessment", EPA/530/SW-137, (March 1975).
3) Haxo, Henry E., Jr., Haxo, Robert S., White, Richard M., "Liner Materials Exposed to Hazardous and Toxic Sludges, First Interim Report", EPA 600/2-77-081 (June 1977).

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Pond Lining (Membrane Linings)	
SPECIFIC DEVICE OR PROCESS Polyvinyl Chloride (PVC)		**NUMBER** 4.1.1.4

	POLLUTANTS CONTROLLED	**AIR** GASES	**AIR** PARTICULATES	**WATER** DISSOLVED	**WATER** SUSPENDED	**LAND** LEACHABLE	**LAND** FUGITIVE
x	**ORGANIC**			x	x	x	
x	**INORGANIC**			x		x	
	THERMAL						
	NOISE						

PROCESS DESCRIPTION

Polyvinyl chloride (PVC) is a plastic membrane available in either unsupported or fabric-reinforced sheeting of 10 to 30 mil thickness. This material contains 30 to 50% plasticizer, 2% chemical stabilizer and a varying amount of filler material. The exact composition can be varied depending upon the application, but in general, it is made in two variations, oil resistant or regular PVC. PVC deteriorates when it is exposed to weather[A]. Consequently, the liner is usually covered as shown in Figure 1. This figure shows the construction details for a lined disposal pond which can be used to store wastewater prior to treatment, disposal, or reuse. In addition, the pond can be used to evaporate the volatile portion of an effluent and to contain any precipitated or settled solids.

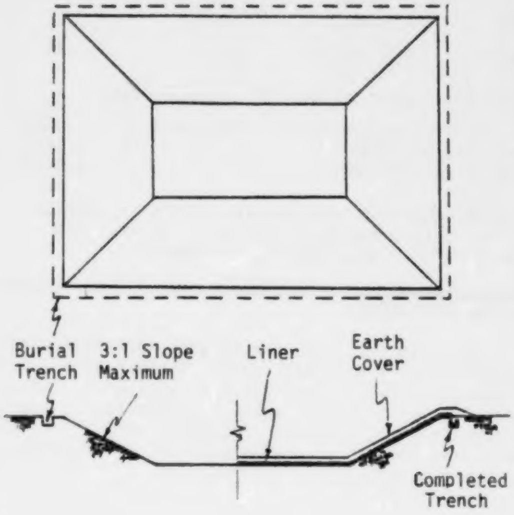


Figure 1. MEMBRANE LINED DISPOSAL POND

Similar to other membrane liners, PVC sheeting is usually made in a continuous process where a thin sheet is formed by passing the compound through the rolls of a calender. PVC can also be reinforced with a fabric (scrim) laminated between two layers. Nylon, dacron, polpropylene, or fiberglass can be used for this purpose. Reinforced liners provide better dimensional stability, better puncture resistance and greater hydrostatic load capacities. However, they also result in less elongation prior to rupture, less conformity to ground irregularities, less flexibility, and greater cost. The tensile strength can range from 3,500 to 10,000 psi, and the elongation from 60 to 200%[B]. The membrane liner is manufactured as a roll-good and fabricated into panels before installation[C]. This reduces the number of field seams which will be required.

PVC is installed in a manner similar to all other membrane liners. The pond is formed and smoothed by conventional methods, and a trench is dug around the perimeter (see Figure 1 left side). The liner is installed and buried in the trench for stability. PVC is relatively easy to splice by solvent welding, adhesive or heat, but it must be done under dry conditions with little or no wind[C]. Bonding PVC to foreign surfaces like concrete may be a problem in some cases. In general, the pond bottom should be slightly sloped (2%) to allow any entrapped air to escape after filling. When the liner installation is complete, an earth cover (6 in. minimum) should be used to protect the liner from weather. This cover will also protect it from mechanical damage and vandalism. If the pit is to be used for burial or landfill (device 4.3.2.4), a cover of 1 to 2 ft should be used.

In some cases, it is extremely important to detect a leak as soon after it is formed as possible. A secondary liner can be provided for this purpose. Leaks if they occur are collected in the secondary liner and drawn off by a separate piping system. Other methods to detect leaks include groundwater monitoring wells, and electrical sensing systems. In some cases this may increase the cost of the pond by as much as two fold.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE Max	60 °C	150°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

APPLICATION RANGE

Oil resistant PVC has good resistance when buried, but in some cases the material may deteriorate due to the biodegradability or solubility of the plasticizers. It has good to excellent resistance to acids and bases, and good resistance to oxygenated, aromatic, halogenated and aliphatic solvents. In some extreme cases, the acid, base and dissolved salt resistance may be questionable. Regular PVC is not applicable to oily wastes especially aromatic solvents.

The above information should be used as a guide. It was not intended for design purposes. A sample should be tested in actual service before a liner material is specified.

CAPITAL COSTS

PVC is the most widely used membrane liner partly because of its low cost. The capital costs for PVC membrane liners are shown below[D]. The costs are January, 1978 costs, and are for material only with no cost break for large quantities. Costs are shown as $/sq ft.

Thickness	Material	Reinforced	Cost
10 mil	PVC	No	.10
20 mil	PVC	No	.16
30 mil	PVC	No	.28
20 mil	O.R. PVC	No	.22
30 mil	O.R. PVC	No	.34

Installation costs can vary as shown below[1].

Cut and Fill Reservoir Construction	\$.02 - \$.05/gal
Liner Installation	\$.02 - \$.06/sq ft
Earth Cover (6" deep)	\$.01 - \$.04/sq ft

The above costs can vary greatly depending upon the location, design and type of liner. Contact the manufacturer for detailed cost information.

OPERATING COSTS

Operating costs include maintenance of the earth cover, monitoring leak detection equipment, and repairing leaks. The maintenance of the earth cover is site specific, and is dependent upon weather conditions and pond design. If a leak is detected, the pond can be drained to expose the liner for repairs. Care must be taken to insure that a clear, dry area is provided for the splice. PVC becomes harder to splice or repair the longer it ages. Electronic bonding can not be used if the liner has been allowed to sun age for as little as 12 to 18 months. Adhesive bonding also becomes difficult in this situation, but methyl ethyl ketone (MEK) can be used to pretreat the surface for better results.

OPERATING EFFICIENCIES

Lined disposal ponds are an effective method for the disposal of liquid effluents. The actual operating efficiency for PVC is impossible to estimate. The major source of emissions are poor splicing and cracks from chemicals that are not compatible with PVC. The permeability for PVC is the highest of all membrane liners ranging from 3 to 18 perm-mils[B].

ENVIRONMENTAL PROBLEMS

Disposal of liquid waste in a lined disposal pond is effective in containing the major portion of the effluent. However, fugitive emissions may be produced from the following two areas:

1) Leaks may develop around seams or at locations where the liner is attacked by the chemicals contained in the liquid waste.

2) Volatile pollutants may be released from the waste liquid as the water is evaporated.

NOTES

A) Operation temperature ranges from -60 to 150°F [B].

B) Source: "Selecting and Installing Synthetic Pond Linings", Chemical Engr. Vol. 80, No. 3, 2/5/73.

C) PVC will become stiff at low temperatures making cold-weather installation a problem.

D) Capital costs are estimated from manufacturer's data.

E) A 5% shrinkage rate must be accounted for with unsupported PVC.

MANUFACTURER / SUPPLIER

Ameron, Plastic Linings Division
B. F. Goodrich Co.
Brown & Brown, Inc.
Burke Rubber Co.
Cooley, Inc.
Crestline
Dearborn Canvas Products Co.
Eastern Gunite Co.
Fabrico Manufacturing Co.
Globe Linings, Inc.
Goodyear Tire & Rubber Co.
Gulf Seal Corp.
Herculite Protective Fabric Corp.
McKitrick Mudd
Pacific Lining Co., Inc.
Palco Linings, Inc.
Pantasote Co.
Plastisteel
Reeves Brother, Inc.
Staff Industies, Inc.
Staflex
Stauffer Chemical Co.
Tennaco Chemical Co.
Unit Liner Co.
Watersaver Co.

REFERENCES

1) Kays, William B., Construction of Linings for Reservoirs, Tanks, and Pollution Control Facilities, John Wiley & Sons, New York, N.Y., (1977).
2) Geswein, Allen J., "Liners for Land Disposal Sites - An Assessment", EPA/530/SW-137, (March 1975).
3) Haxo, Henry E., Jr., Haxo, Robert S., White, Richard M., "Liner Materials Explosed to Hazardous and Toxic Sludges, First Interim Report", EPA 600/2-77-081 (June 1977).

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Final Disposal	Pond Lining (Membrane Linings)

SPECIFIC DEVICE OR PROCESS	NUMBER
Chlorosulfonated Polyethylene (Hypalon)	4.1.1.5

POLLUTANTS CONTROLLED	AIR		WATER		LAND	
	GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
x ORGANIC			x	x	x	
x INORGANIC			x		x	
THERMAL						
NOISE						

PROCESS DESCRIPTION

Chlorosulfonated polyethylene (Hypalon[A]) is produced by reacting ethylene with chlorine and sulfur. The uncured rubber compound which is produced can be used as a pond liner, and is available in fabric-reinforced sheeting of 30 to 45 mil-thickness. This material is produced in two grades, Hypalon-45 and Hypalon-48. The latter is more difficult to produce but it does have a better oil resistance. It also has good resistance to ozone and ultraviolet light. Consequently, it can be used without an earth cover, and can withstand adverse weather conditions[B]. Figure 1 shows a schematic diagram of a lined disposal pond which can be used to store wastewater prior to treatment, disposal, or reuse. In addition, the pond can be used to evaporate the volatile portion of an effluent and to contain any precipitated or settled solids.

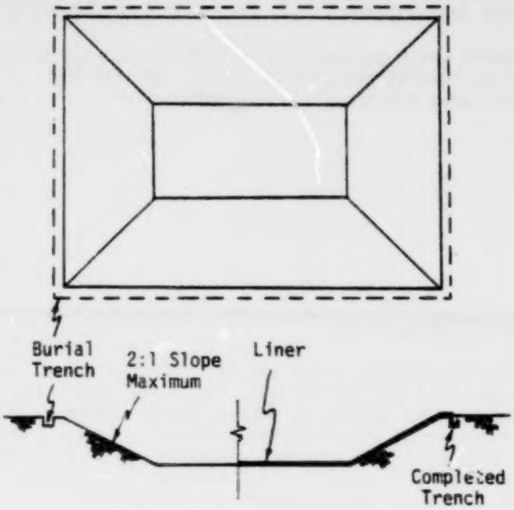


Figure 1. MEMBRANE LINED DISPOSAL POND

Hypalon sheeting is usually made in a continous process plying together two thin sheets formed by passing the compound through the rolls of a calender. Plying two sheets together in this manner almost eliminates pinholes. Hypalon is usually reinforced with a fabric (scrim) laminated between the layers. Nylon and polyester are used for this purpose. This provides better dimensional stability, better puncture resistance and greater hydrostatic load capacities. However, it also results in less elongation prior to rupture, less conformity to ground irregularities, less flexibility, and greater cost. The tensile strength for Hypalon can range from 1000 to 2000 psi, and the elongation from 55 to 95%[C]. The membrane liner is manufactured as a roll-good and fabricated into panels before installation. Additional material must be provided to allow for shrinkage, 0.5% for supported and 32% for unsupported Hypalon.

Hypalon is installed in a manner similar to all other membrane liners. The pond is formed and smoothed by conventional methods, and a trench is dug around the perimeter (see Figure 1 left side). The liner is installed and buried in the trench for stability. Hypalon is easy to seam in the factory or in the field with solvents, cements, heat or by electronic bonding[D]. Adhesive systems are available for bonding to foreign surfaces. In general, the pond bottom should be slightly sloped (2%) to allow any entrapped air to escape after filling.

In some cases, it is extremely important to detect a leak as soon after it is formed as possible. A secondary liner can be provided for this purpose. Leaks if they occur are collected in the secondary liner and drawn off by a separate piping system. Other methods to detect leaks include groundwater monitoring wells, and electrical sensing systems. In some cases this may increase the cost of the pond by as much as two fold.

Hypalon can be used in lined burial pits (device 4.3.2.4) but the liner should be buried with an earth cover of 1 to 2 ft to prevent liner damage. Earth covers can also be used to prevent physical damage and vandalism, or to provide a natural bottom as in fish culture and in esthetic landscaping.

APPLICATION RANGE

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE Max	60 °C	150°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

Hypalon has excellent resistance to weathering, aging, oil, and bacteria. It is also good in applications with highly acid containing wastes. Resistance has been reported as good to excellent in bases; good in oxygenated solvents and aliphatic (petroleum) solvents; and poor in aromatic and halogenated solvents. In extreme conditions, it may have questionable service in petroleum sludges, and other dissolved organics. It is not acceptable in contact with oxidizing acids.

The above information should be used as a guide. It was not intended for design purposes. A sample should be tested in actual service before a liner material is specified.

CAPITAL COSTS

The capital costs for Hypalon membrane liners are shown below[c]. The costs are January, 1978 costs, and are for material only with no cost break for large quantities. Costs are shown as $/sq ft.

Thickness	Reinforced	Cost
36 mil	Yes	0.52

Installation costs can vary as shown below[1].

Cut and Fill Reservoir Construction	\$.02 - \$.05/gal
Liner Installation	\$.02 - \$.06/sq ft

The above costs can vary greatly depending upon the location, design and type of liner. Contact the manufacturer for detailed cost information.

OPERATING COSTS

Operating costs include maintenance of the earth cover (if included), monitoring leak detection equipment, and repairing leaks. The maintenance of the earth cover is site specific, and is dependent upon weather conditions and pond design. If a leak is detected, the pond can be drained to expose the liner for repairs. Care must be taken to insure that a clean, dry area is provided for the splice. Hypalon cures with age which may cause problems in repair work. As aging progresses, certain solvents and adhesives may be hard to use. Alternate adhesive formulations are available and must be used with a surface pretreatment. Shrinkage of the patch may also be a problem when repairing with unsupported Hypalon.

OPERATING EFFICIENCIES

Lined disposal ponds are an effective method for disposal of liquid effluents. The actual operating efficiency for Hypalon is impossible to estimate. The major source of emissions are poor splicing and cracks from chemicals that are not compatible with the liner. The permeability specified for Hypalon is 2.0 perm-mils[C]. In most cases, however, a permeability of essentially zero can be realized.

ENVIRONMENTAL PROBLEMS

Disposal of liquid waste in a lined disposal pond is effective in containing the major portion of the effluent. However, fugitive emissions may be produced from the following two areas:

1) Leaks may develop around seams or at locations where the liner is attacked by the chemicals contained in the liquid waste.

2) Volatile pollutants may be released from the waste liquid as the water is evaporated.

NOTES

A) Hypalon is a registered trademark of DuPont.

B) Operating temperature ranges from -45 to 150°F[C].

C) Source: "Selecting and Installing Synthetic Pond Linings", Chemical Engr. Vol 80, No. 3, 2/5/73.

D) Hypalon can be seamed in cold or wet field conditions. A heater may be required to speed the process in cold weather.

E) Capital costs are estimated from manufacturer's data.

MANUFACTURER/SUPPLIER

AeroTec Labs, Inc.
B. F. Goodrich Co.
Brown & Brown, Inc.
Burke Rubber Co.
Cooley, Inc.
Crestline
Dearborn Canvas Products Co.
Dunline Ltd.
Eastern Gunite Co.
E. I. duPont de Nemours & Co., Inc.
Fabrico Manufacturing Co.
Globe Linings, Inc.
Gulf Seal Corp.
McKitrick Mudd
Misco-United Supply, Inc.
Pacific Lining Co., Inc.
Plastisteel
Plymouth Rubber Co.
Richardson Co., The
Staff Industries, Inc.
Staflex
Stevens Elastomeric &
  Plastic Products Co.
Watersaver Co.

REFERENCES

1) Kays, William B., Construction of Linings for Reservoirs, Tanks, and Pollution Control Facilities, John Wiley & Sons, New York, N.Y., (1977).
2) Geswein, Allen J., "Liners for Land Disposal Sites - An Assessment", EPA/530/SW-137, (March 1975).
3) Haxo, Henry E., Jr., Haxo, Robert S., White, Richard M., "Liner Materials Exposed to Hazardous and Toxic Sludges, First Interim Report", EPA 600/2-77-081 (June 1977).

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Pond Lining (Membrane Linings)
SPECIFIC DEVICE OR PROCESS Chlorinated Polyethylene (CPE)	**NUMBER** 4.1.1.6

POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
	GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
X **ORGANIC**			X	X	X	
X **INORGANIC**			X	X	X	
THERMAL						
NOISE						

PROCESS DESCRIPTION

Chlorinated Polyethylene (CPE) is a polymer produced by the chlorination of high density polyethylene. In its final form, CPE is a very flexible thermoplastic material and is available in unsupported or fabric-reinforced sheets of 20 to 40 mil thickness. It is highly resistant to ozone, ultraviolet light, and adverse weather conditions^{A}. Consequently, it has excellent weatherability and can be installed without an earth cover as shown in Figure 1. This pond can be used to store wastewater prior to treatment, disposal, or reuse; to evaporate the volatile portion of an effluent; and to contain any precipitated or settled solids.

Similar to other membrane liners, CPE sheeting is usually made in a continuous process where a thin sheet is formed by passing the compound through the rolls of a calender. It has a unique compatability with other plastics and has been alloyed (blended) with polyethylene, polyvinyl chloride (PVC), and acrylonitrile butadiene styrene (ABS). Blends of this nature result in better physical properties (eg. crack resistance, tensile strength and elongation). This also improves chemical resistance. CPE can also be reinforced with a fabric (scrim) laminated between two layers. Nylon, dacron, polypropylene, or fiberglass can be used for this purpose. Reinforced liners also provide better physical properties (eg. dimensional stability, puncture resistance, and hydrostatic load capacities). However, they also result in less elongation prior to rupture, less conformity to ground irregularities, less flexibility, and greater cost. The tensile strength is specified as 1800 psi minimum and the elongation can range from 375 to 575%^{B}. The membrane liner is manufactured as a roll-good and sent to a fabricator where the material is joined together to form panels before installation.

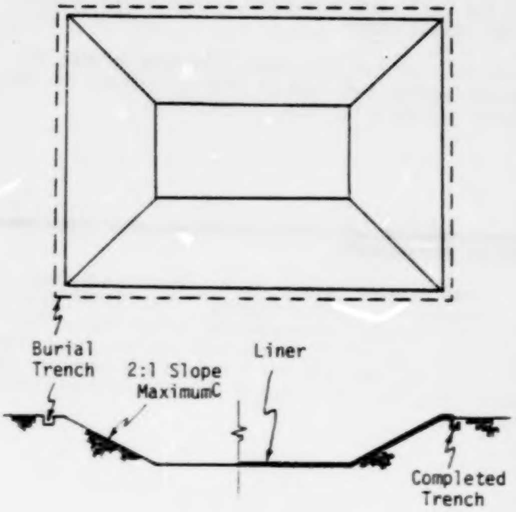


Figure 1. MEMBRANE LINED DISPOSAL POND

CPE is installed in a manner similar to all other membrane liners. The pond is formed and smoothed by conventional methods, and a trench is dug around the perimeter (see Figure 1 left side). The liner is installed and buried in the trench for stability. In general, the pond bottom should be slightly sloped (2%) to allow any entrapped air to escape after filling. It is relatively easy to seam with solvent adhesives, solvent welding, heat and dielectric welding. CPE can also be seamed to PVC (4.1.1.4) for a combination liner.

In some cases, it is extremely important to detect a leak immediately after it is formed. A secondary liner can be provided for this purpose. Leaks if they occur are collected in the secondary liner and drawn off by a separate piping system. Other methods to detect leaks include groundwater monitoring wells, and electrical sensing systems. In some cases this may increase the cost of the pond by as much as two fold.

CPE can be used in lined burial pits (device 4.3.2.4) but the liner should be buried with an earth cover of 1 to 2 ft to prevent liner damage. Earth covers can also be used to prevent physical damage and vandalism, or to provide a natural bottom as in fish culture or in esthetic landscaping.

APPLICATION RANGE

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE Max	90 °C	200 °F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

Chlorinated Polyethylene provides good to excellent service in acids and bases; good service in aliphatic (petroleum) solvents, hydrocarons, and salt solutions; and poor service in oxygenated solvents, aromatic and halogenated solvents, fats and greases. In some extreme cases CPE may have questionable service in strong bases and concentrated salt solutions. CPE has excellent weatherability, and resists microbiological attack and burning.

The above information should be used as a guide. It was not intended for design purposes. A sample should be tested in actual service before a liner material is specified.

CAPITAL COSTS

The capital costs for CPE membrane liners are shown below[D]. The costs are January, 1978 costs, and are for material only with no cost break for large quantities. Costs are shown as $/sq ft.

Thickness	Reinforced	Cost
20 mil	no	0.23
30 mil	no	0.35
30 mil	yes	0.52

Installation costs can vary as shown below[1].

Cut and Fill Reservoir Construction	$.02 - $.05/gal
Liner Installation	$.02 - $.06/sq ft

The above costs can vary greatly depending upon the location, design and type of liner. Contact the manufacturer for detailed cost information.

OPERATING COSTS

Operating costs include maintenance of the earth cover (if included), monitoring leak detection equipment, and repairing leaks. The maintenance of the earth cover is site specific, and is dependent upon weather conditions and pond design. If a leak is detected, the pond can be drained to expose the liner for repairs. Care must be taken to insure that a clean, dry area is provided for the splice.

OPERATING EFFICIENCIES

Lined disposal ponds are an effective method for the disposal of liquid effluents. The actual operating efficiency for CPE is impossible to estimate. The major source of emissions are poor splicing and cracks from chemicals that are not compatible with CPE. The permeability for CPE ranges from 0.040 to 0.048 perm-mils[B].

ENVIRONMENTAL PROBLEMS

Disposal of liquid waste in a lined disposal pond is effective in containing the major portion of the effluent. However, fugitive emissions may be produced from the following two areas:

1) Leaks may develop around seams or at locations where the liner is attacked by the chemicals contained in the liquid waste.

2) Volatile pollutants may be released from the waste liquid as the water is evaporated.

NOTES

A) Operating temperature range is -40 to 200°F.

B) Source: "Selecting and Installing Synthetic Pond Linings", Chemical Engr. Vol. 80, No. 3, 2/5/73.

C) A slope of 2:1 can be used with supported CPE. Unsupported material cannot be used on slopes greater than 3:1.

D) Capital costs are estimated from manufacturer's data.

MANUFACTURER / SUPPLIER

B. F. Goodrich Co.
Brown & Brown, Inc.
Cooley, Inc.
Crestline
Dearborn Canvas Products Co.
Dow Chemical Co.
Eastern Gunite Co.
Fabrico Manufacturing Co.
Globe Linings, Inc.
Gulf Seal Corp.
McKitrick Mudd
Pacific Lining Co., Inc.
Palco Linings, Inc.
Pantasote Co.
Plastisteel
Staff Industries, Inc.
Staflex
Stevens Elastomeric & Plastic Products Co.
Watersaver Co.

REFERENCES

1) Kays, William B., Construction of Linings for Reservoirs, Tanks, and Pollution Control Facilities, John Wiley & Sons, New York, N.Y., (1977).
2) Geswein, Allen J., "Liners for Land Disposal Sites - An Assessment", EPA/530/SW-137, (March 1975).
3) Haxo, Henry E., Jr., Haxo, Robert S., White, Richard M., "Liner Materials Exposed to Hazardous and Toxic Sludges, First Interim Report", EPA 600/2-77-081 (June 1977).

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Pond Lining (Membrane Linings)

SPECIFIC DEVICE OR PROCESS Polyolefin (3110)	**NUMBER** 4.1.1.10

POLLUTANTS CONTROLLED		AIR		WATER		LAND	
		GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
x	ORGANIC			X	X	X	
x	INORGANIC			X		X	
	THERMAL						
	NOISE						

PROCESS DESCRIPTION

Elasticized polyolefin (3110^A) is a thermoplastic material, and is available in unsupported sheets of 20 to 30 mil thicknesses. It is produced by a copolymerization of an olefin and one of the synthetic rubber monomers, without vulcanization. "3110" uses a nonmigrating polymer as a plasticizer. Consequently, it has excellent weatherability and can be used without an earth cover. Figure 1 shows a schematic diagram of the lined disposal pond which can be used to store wastewater prior to treatment, disposal, or reuse. In addition, the pond can be used to evaporate the volatile portion of an effleunt and to contain any precipitated or settled solids.

Polyolefin is manufactured in 20 ft. wide seamless sheets on a blown film extruding machine. The material is rolled onto tubes and shipped directly to the jobsite, or to a fabricator where the liner is joined together to form larger panels before installation. The panels can be made to fit the pond exactly because "3110" does not shrink with time. The specifications for the finished product show a minimum tensile strength of 2300 psi and a minimum elongation at break of 500%, after 14 days of heat aging at 212°F^B.

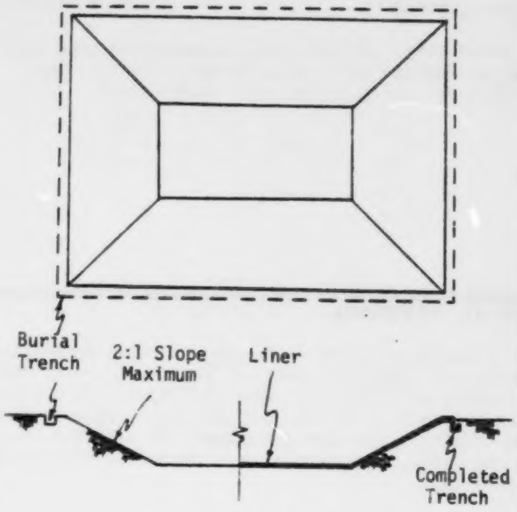


Figure 1. MEMBRANE LINED DISPOSAL POND

Polyolefin is installed in a manner similar to all other liners. The pond is formed and smoothed by conventional methods, and a trench is dug around the perimeter (see Figure 1 left side). The liner is installed and buried in the trench for stability. Polyolefin is heat seamed in either the factory or field with a portable hand held electric welder. This process is not affected by weather conditions and can be done even in the rain^C. A two-part epoxy-type resin is used to bond the liner to foreign surfaces like concrete, steel or wood. This is usually done in conjunction with standard mechanical anchoring. In general, the pond bottom should be slightly sloped (2%) to allow any entrapped air to escape after filling.

In some cases, it is extremely important to detect a leak immediately after it is formed. A secondary liner can be provided for this purpose. Leaks if they occur are collected in the secondary liner and drawn off by a separate piping system. Other methods to detect leaks include groundwater monitoring wells, and electrical sensing systems. In some cases this may increase the cost of the pond by as much as two fold.

Polyolefin can be used in lined burial pits (device 4.3.2.4) but the liner should be buried with an earth cover 1 to 2 ft to prevent liner damage. Earth covers can also be used to prevent physical damage or vandalism. In addition, they may be required to provide a natural bottom for fish culture or in esthetic landscaping.

APPLICATION RANGE

Polyolefin is not affected when used in applications involving acids, bases, organic acids, alcohols, vegetable oils, brines and other salt solutions. It has questionable service in concentrated sulfuric acid, benzene, gasoline, acetone and some ketones. "3110" is not recommended for use in saturated and unsaturated oils, aromatic solvents, perchloroethylene, mineral oil, phenol, carbon tetrachloride and certain petroleum products.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE Max	70 °C	160°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

The above information should be used as a guide. It is not intended for design purposes. A sample should be tested in actual service before a liner material is specified.

CAPITAL COSTS

The capital costs for polyolefin membrane liners are shown below[D]. The costs are January, 1978 costs, and are for material only with no cost break for large quantities. Costs are shown as $/sq ft.

Thickness	Reinforced	Cost
20 mil	No	0.25

Installation costs can vary as shown below[1].

Cut and Fill Reservoir Construction	$.02 - $.05/gal
Liner Installation	$.02 - $.06/sq ft

The above costs can vary greatly depending upon the location, design and type of liner. Contact the manufacturer for detailed cost information.

OPERATING COSTS

Operating costs include maintenance of the earth cover (if included), monitoring leak detection equipment, and repairing leaks. The maintenance of the earth cover is site specific, and is dependent upon weather conditions and pond design. If a leak is detected, the pond can be drained to expose the liner for repairs. Care must be taken to insure that a clean, dry area is provided for the splice. The repair procedure is complicated and involves 4 steps. First the material to be repaired is welded to a backup piece of cardboard. Then the patch is laid down and covered with a clear film of high-temperature-resistant Kapton film. Heat is applied by a flameless heat gun. The softened film and patch are bonded to the liner by applying pressure with a seam roller.

OPERATING EFFICIENCIES

Lined disposal ponds are an effective method for disposal of liquid effluents. The actual operating efficiency for "3110" is impossible to estimate. The major source of emissions are poor splicing and cracks from chemicals that are not compatible with the liner. In most cases, a permeability of essentially zero can be realized.

ENVIRONMENTAL PROBLEMS

Disposal of liquid wastes in a lined disposal pond is effective in containing the major portion of the effluent. However, fugitive emissions may be produced from the following two areas:

1) Leaks may develop around seams or at locations where the liner is attacked by the chemicals contained in the liquid waste.

2) Volatile pollutants may be released from the waste liquid as the water is evaporated.

NOTES

A) "3110" is a DuPont trademark for elasticized polyolefin sheeting.

B) Heat aging was done according to ASTM-412. Tensile strength and elongation at break were done according to ASTM-882-73.

C) Installation can be done at any temperature but experience shows 60 to 85°F to be the best.

D) Capital costs are estimated from manufacturer's data.

MANUFACTURER/SUPPLIER

B. F. Goodrich Co.
Burke Rubber Co.
Crestline
Dunline, Ltd.
Eastern Gunite Co.
E.I. duPont de Nemours & Co., Inc.
Globe Linings, Inc.
Gulf Seal Corp.
McKitrick Mudd
Misco-United Supply, Inc.
Pacific Lining Co., Inc.
Plymouth Rubber Co.
Staflex
Watersaver Co.

REFERENCES

1) Kays, William B., Construction of Linings for Reservoirs, Tanks, and Pollution Control Facilities, John Wiley & Sons, New York, N.Y., (1977).
2) Geswein, Allen J., "Liners for Land Disposal Sites - An Assessment", EPA/530/SW-137, (March 1975).
3) Haxo, Henry E., Jr., Haxo, Robert S., White, Richard M., "Liner Materials Exposed to Hazardous and Toxic Sludges, First Interim Report", EPA 600/2-77-081 (June 1977).

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Deep Well Injection (Injection Techniques)	
SPECIFIC DEVICE OR PROCESS Hydraulic Fracturing		**NUMBER** 4.2.2.6

POLLUTANTS CONTROLLED	AIR		WATER		LAND	
	GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
☒ ORGANIC			X	X		
☒ INORGANIC			X	X		
☐ THERMAL						
☐ NOISE						

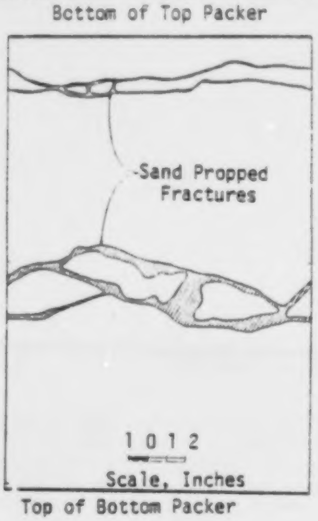


Figure 1

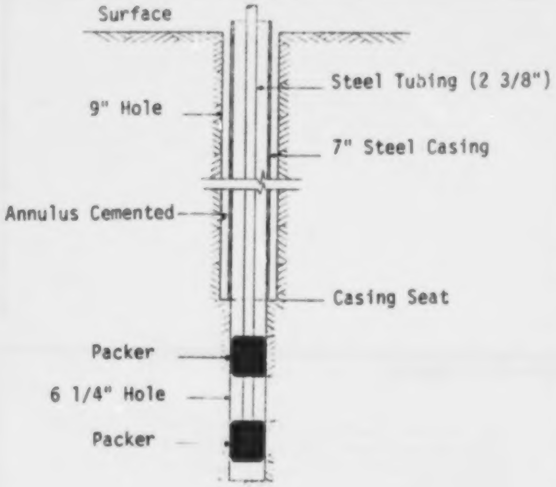


Figure 2

Process Description

Hydraulic fracturing of the formation rock is used to increase the injectivity of new injection wells and to rejuvenate old wells that have become saturated with suspended solids.

Injecting fluids into the rock produces fractures which radiate out from the center of the well. When formation breakdown occurs "frac" sand or other propping agents are injected into the fractures to maintain permeability. Fracturing the rock in this way increases the effective permeability thus allowing lower pressures to be used in waste injection, as shown in Figure 1.

Figure 2, illustrates a typical hydraulic fracturing system. The fracturing treatment is performed between double (straddle) packers and 2" to 3" steel tubing. The interval to be fractured was sealed off by pressurizing the packers with water (1500 to 2000 psi). Fluid access to the formation rock between the packers was made through injection ports in the steel tubing. Water and water base gels are used as the injection mediums. Pressures needed to fracture rock may run as high as 1500 to 2000 psi with pumping rates ranging from 2 bbls/min to 8 bbls/min.

Application Range

Hydraulic fracturing is used where the effective permeability of the rock is insufficient to permit flow of the waste materials into the formation at the desired pressure and rate.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Hydraulic Fracturing is done on a sub-contract basis and therefore capital costs need not be taken into account.

OPERATING COSTS

As with capital costs, the operating costs would be included in the sub-contract bid.

There are no additional operating costs foreseen for a well that has to be treated as opposed to a non-treated well.

OPERATING EFFICIENCIES

Due to the fact that this is a well preparation process and not an actual method of disposal, efficiencies can not be logically formulated.

ENVIRONMENTAL PROBLEMS

The major environmental problem of concern would be pollution of ground water sources in the area around the injection well. Complete hydrology studies of the disposal area will have to be done to assure the safety of the ground water system.

NOTES

A. See local oil and gas well servicing agents.

MANUFACTURER / SUPPLIER/CONTRACTORS
Partial List[A]

Dowell
Halliburton Services
BJ Hughes

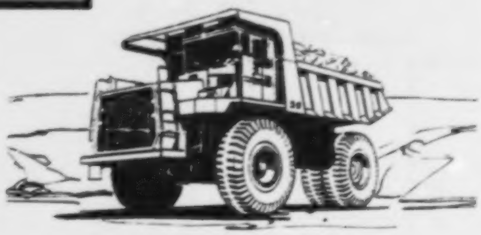
REFERENCES

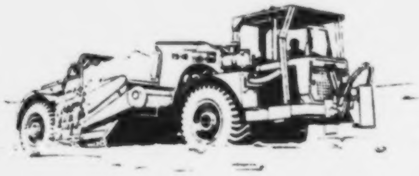
1.) Donaldson, Erle C., "Subsurface Disposal of Industrial Wastes in the United States," Bureau of Mines Information Circular 8212, (1964).

2.) Carpenter, H.C., Sterner, T.E., "Hydraulic Fracturing of Wyoming Green River Oil Shale: Field Experiments, Phase I," Bureau of Mines Report of Investigations 7596, (1972).

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Burial and Landfill - Transportation
SPECIFIC DEVICE OR PROCESS Trucks and Scrapers	**NUMBER** 4.3.1.3

	POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
		GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
	ORGANIC						
x	**INORGANIC**						x Refuse-Ash
	THERMAL						
	NOISE						





Process Description

The disposal of solid wastes by truck or scraper can be very economical and offer a versatile system of refuse disposal. Waste material may be hauled directly from a truck hopper or it may be received from a conveyor system.

Scrapers are useful when grades are rough and steep and the haulage runs are short. When large amounts of waste are to be hauled long distances and the road conditions are good, the haulage truck proves to be the better answer. The disposal system will become more reliable and its capacity will increase when more than one haulage unit is used.

Due to the versatility of haulage trucks and scrapers, a greater flexibility in the construction and location of the solid waste disposal areas can be allowed. Trucks and scrapers can gain access to difficult terrain, and help in spreading and compacting the refuse while unloading.

In almost every case a bulldozer will be required to doze and maintain the refuse storage areas. A bulldozer may also be required to help load scrapers of the "standard" or "push-pull" type. Elevating scrapers are capable of loading themselves without assistance from other equipment.

Haul road maintenance is of vital importance to the success of the disposal system. Poor roads will decrease vehicle speed, increase fuel and maintenance costs, and cause driver fatigue. Well trained drivers and a good maintenance program will enhance the reliability of the solid waste haulage system.

Application Range

Solid waste disposal by truck or scraper can be used effectively in almost any climate and terrain. The capacity of the system can be varied by merely adding or subtracting haulage units. Location of the disposal site is dependent upon the accessability and the distance from the source of the waste material to the disposal site.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

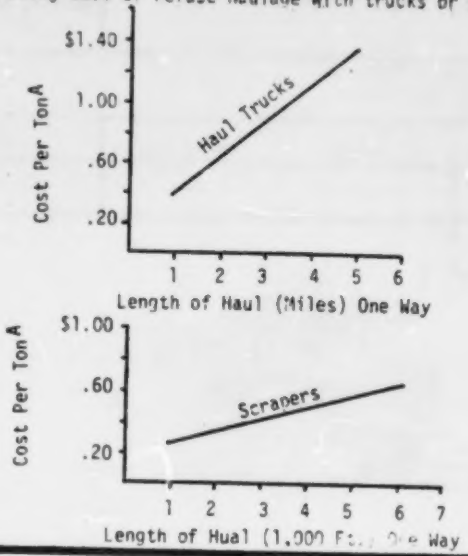
Rear Dump Haulage Trucks:	$150,000 to $400,000
Capacity:	35 Ton to 85 Ton
Scrapers	$150,000 to $350,000
Capacity:	11 yd^3 to 30 yd^3

*The costs and capacities listed are those for equipment felt suitable for this task.[A]

October 1977

OPERATING COSTS

Operating cost of refuse haulage with trucks or scrapers



OPERATING EFFICIENCIES

Due to the fact that this is an intermediate process in the disposal of solid wastes no disposal efficiencies can be logically formulated.

ENVIRONMENTAL PROBLEMS

The only environmental problems of any concern associated with the transportation of solid wastes are in the following areas:

- Fugitive emissions
- Spillage of wastes along haulage route.

NOTES

A) All capital and operating costs are for hauling expenses only. Haul road construction and maintenance as well as bulldozer costs are not included.

MANUFACTURER / SUPPLIER

Trucks & Tractor-Trailers

Athey Products Corp.
Atlas Hoist & Body Inc.
Catepillar Tractor Co.
Challenge-Cook Bros., Inc.
Cushman-OMC-Lincoln
Dart Truck Co.
Eimco Mining Machinery
Euclid, Inc.
Fairbanks Co.
Ford Motor Co.
Fruehauf Div.
Geo Space Corp.
Goodbary Equip. Co.
International Harvester
Iowa Mold Tooling Co.
ISCO mfg. Co.
Kenworth Truck Co.
Kockums Ind. AB
Kress Corp.
Mack Trucks, Inc.
Midway Equip., Inc.
Oshkosh Truck Corp.
Rimpull Corp.
Rish Equip. Co., Intl.
Terex Div., GMC
WABSO Construction & Mining Equip. Group
Wagner Mining Equip.
White Motor Corp.

Scrapers

Caterpiller
Clark Equip. Co.
Deere & Co.
Fiat-Allis
Ford Tractor Opt.
Hanson, R.A.
Intl. Harvester
Midway Equipment
Rish Equipment
Terex Division
WABCO Const. & Mining

REFERENCES

1.) Mitchell, David R., and Leonard, Joseph W., ed. Coal Preparation, AIME, New York, Second Edition, (1950); Third Edition, (1968).
2.) Wagner Equipment Co., 6000 Dahlia Street, Denver, Colorado.
3.) "Production and Cost Estimating of Material Movement With Earthmoving Equipment", Terex Division, General Motors Corporation, Hudson, Ohio.
4.) "Coal Age", Volume 81-Number 9-September 1976, McGraw Hill, New York.

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Burial and Landfill
SPECIFIC DEVICE OR PROCESS Deep Slurry Impoundment	**NUMBER** 4.3.2.1

POLLUTANTS CONTROLLED		**AIR**			**WATER**				**LAND**		
		GASES		**PARTICULATES**		**DISSOLVED**		**SUSPENDED**		**LEACHABLE**		**FUGITIVE**
☐	**ORGANIC**	☐		☐		☐		☐		☐		☐	
x	**INORGANIC**	☐		☐		☐		☐		☐		x	Refuse, Ash
☐	**THERMAL**												
☐	**NOISE**												

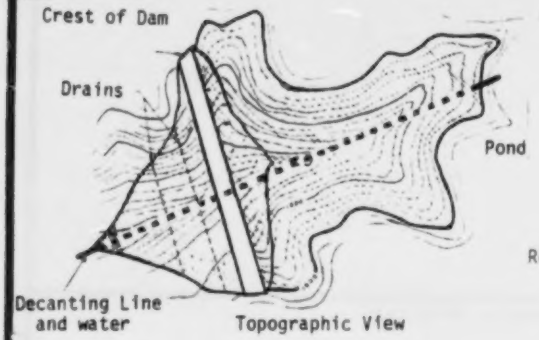


Figure 1.

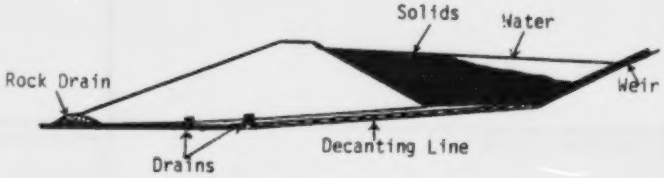


Figure 2.

Process Description

As shown in Figure 1, deep slurry impoundments are small in area and are located behind dams constructed across deep ravines in mountainous or hilly terrain.

The location, design, and erection of impoundment dams will require careful baseline investigations before any construction can begin. Ground water studies should be conducted so as to determine if any possible pollution or alterations to the local hydrological system will occur. Inspection of the local topography, soils, rock strata, and the available dam building materials must be made to assure proper design and construction of the impoundment dam. The area's climate and rainfall records must be checked to find the frequency of "cloud burst" that could possibly weaken, overflow or even cause the dam to fail. Spillways, drains or diversion ditches should be used if possible to alleviate floodwater problems. The dam should be located at the head of the ravine or valley so as to reduce the amount of natural drainage into the impoundment area. Dams may fail because of erosion at the top of the dam; lack of drainage under the dam or by using unstable building materials. Natural disasters such as earthquakes, major floods and etc. may of course cause dam failure and these factors should be taken into account before final design and erection.

The cross section shown in Figure 2 shows the basic components of a dam used for slurry impoundment. When the slurry enters the impoundment the solid fines settle out allowing the clear water to be decanted off. Note the drains, the decanting line and the weir which not only allow proper drainage under the dam but also enable the slurry water, once free of the suspended solids, to be released.

The safety of the people and the property in the drainage area below the dam must be of prime consideration before any planning or action takes place.

Application Range

Deep slurry impoundments can be used in areas only after careful study has found them to be safe, stable, and relatively free of hazards which could cause dam failure. The fine refuse that is dumped into the impoundment should not be hazardous to the local groundwater system or to the surface environment.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Capital costs cannot be accurately displayed due to the many varying economic and labor factors involved in the construction of an impoundment system. It must be stressed that careful study and the use of the best building materials available be considered to assure proper construction of the dam. Capital costs should include, in addition to the construction costs, probable land costs, water rights, rights of way, land clearing, structure relocation costs (if any), engineering, and administration costs.

OPERATING COSTS

Because of widely varying economic and labor conditions in different localities it is not possible to furnish operating costs (if any). The operating costs of concern would include dam maintenance, dredging, decanting system maintenance, and final waste containment.

OPERATING EFFICIENCIES

If constructed properly the deep slurry impoundment system should eliminate virturally all of the fine particulates in the slurry. The system will do little to eliminate harsh chemicals dissolved in the effluent.

ENVIRONMENTAL PROBLEMS

The environmental problem of concern would involve fugitive emissions of dissolved harsh chemicals in the slurry water contaminating the ground water or the drainage systems below the impoundment site. Once the slurry pond has filled with the settled fines a proper method of disposing of the solid refuse must be found and implemented.

NOTES

MANUFACTURER / SUPPLIER

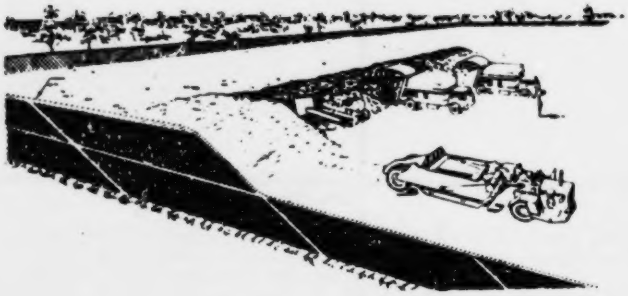
REFERENCES

1.) Mitchell, David R., and Leonard, Joseph W., ed., Coal Preparation, AIME, New York, Second Edition, (1950): Third Edition, (1968).

2.) U.S. Bureau of Reclamation, Design of Small Dams, A Water Resource Publication, Second Edition, (1973), Revised Reprint, (1974).

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Burial and Landfill
SPECIFIC DEVICE OR PROCESS Layered Flat Land Disposal	**NUMBER** 4.3.2.2

	POLLUTANTS CONTROLLED		**AIR** GASES		**AIR** PARTICULATES		**WATER** DISSOLVED		**WATER** SUSPENDED		**LAND** LEACHABLE		**LAND** FUGITIVE
	ORGANIC												
X	**INORGANIC**											X	Refuse, Ash
	THERMAL												
	NOISE												



(Courtesy of Office of Solid Waste Management Programs,
U.S. Environmental Protection Agency)

PROCESS DESCRIPTION

Layered flat land disposal involves the dumping of refuse on undisturbed existing ground surface. The only site preparation work would involve stripping the topsoil to be used later for final cover of the waste material.

The refuse, once dumped, is spread and compacted by scrapers and dozers. The waste will be spread in uniform layers until the entire disposal site has been filled. When the final layer has been deposited, the topsoil that was stripped off earlier will be replaced over the fill. This method works best when the terrain is slightly irregular allowing for better containment of the waste material. The working face must be large enough to allow for efficient dumping of the refuse haulers without causing any delays. It must also be noted that an operating area that is oversized is difficult to maintain and could result in problems with dust control and the leaching of the waste. The size of the area will depend on the plant production of waste materials, haul truck size and maneuverability, climate, and other factors.

APPLICATION RANGE

Layered flat land disposal is used where trenchs, ditches, ravines, and small valleys cannot be found for use as disposal areas. Due to the large area that is covered by this method it may not be practical to line the surface prior to any disposal operations. For this reason, the wastes that are dumped must not be hazardous to the surrounding land or have any harmful compounds that might be leached into the soil or groundwater systems.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Capital costs cannot be accurately displayed due to the many varying economic and labor factors in the construction of permanent waste storage systems. Capital costs should include, in addition to the construction costs, probable land costs, water rights, rights of way, land clearing, engineering, and administration costs.

OPERATING COSTS

Because of widely varying economic and labor conditions in different localities, it is not possible to furnish operating costs (if any). The operating costs of concern would include site maintenance, waste spreading and compacting and final waste sealing and covering.

OPERATING EFFICIENCIES

Layered area disposal systems should provide a safe and hazard-free method of permanently storing waste materials. The material is a solid when disposed of, the problem is in rain leaching the waste that has been oxidized. The system will do little to eliminate the harsh chemicals that have been leached by the rain from the oxidized waste.

ENVIRONMENTAL PROBLEMS

The environmental problems of concern would involve leaching harsh chemicals in the wastes contaminating the groundwater or drainage systems below the site. Also fugitive dust while the waste is being spread. Once the area has been filled a method for properly sealing and covering the wastes should be implemented.

NOTES

MANUFACTURER / SUPPLIER

REFERENCES

1) Liptak, B. G., ed., Environmental Engineers Handbook - Volume 3 - Land Pollution, Chilton Book Co., Rodnor, Pa., (1974)..

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Burial and Landfill	
SPECIFIC DEVICE OR PROCESS Layered Ravine Disposal		**NUMBER** 4.3.2.3

POLLUTANTS CONTROLLED		**AIR**		**WATER**		**LAND**	
		GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
	ORGANIC						
x	**INORGANIC**						x Refuse, Ash
	THERMAL						
	NOISE						

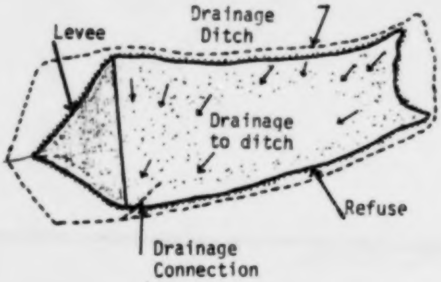


Figure 1

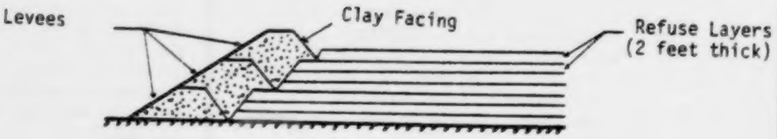


Figure 2

Process Description

The layered ravine disposal method shown in Figure 1 is used when the refuse is of a spontaneously combustable nature. In many areas there exists insufficient amounts of clay-like material to completely cover and seal the refuse material. By spreading and compacting the refuse in thin layers (two feet) in ravines the waste material can be allowed to weather and oxidize until it becomes incombustable. After a weathering period of about a year, another layer can be spread and compacted over the previous layer. While the waste layering is in progress, a small clay levee is placed at the down drainage edge of the pile as shown in Figure 2. The clay levee prevents any waste water and refuse material from entering the drainage system. As the refuse layers accumulate new clay levees are built on top of the previous levees. To help the levees stay in place, grass and shrubbery can be planted to prevent erosion from wind and rain. Scrapers and dozers can be used both to spread and compact the refuse. They can also be used to build and sustain the levees. Once the ravines have been filled with refuse, they must be covered with a sealing material and seeded.

If the refuse is of a highly combustable nature it may be advisable to add a high-ash refuse filter cake (at least 50 percent if available) to prevent the possibility of spontaneous combustion in the refuse layers. As with any final disposal system involving dams or levees careful studies must be made to insure against levee failure and the pollution of the drainage system by fugitive emissions from the oxidizing wastes.

Application Range

Layered ravine disposal systems are used when the refuse is of combustable nature. They can be used wherever insufficient amounts of proper sealing material exists to cover large waste disposal areas. The refuse that is dumped should not be hazardous to the local groundwater system or to the surface environment.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Capital costs cannot be accurately displayed due to the many varying economic and labor factors in the construction of permanent waste storage systems. Capital costs should include, in addition to the construction costs, probable land costs, water rights, rights of way, land clearing, engineering, and administration costs.

OPERATING COSTS

Because of widely varying economic and labor conditions in different localities, it is not possible to furnish operating costs (if any). The operating costs of concern would include levee maintenance, waste spreading and compacting and final waste sealing and covering.

OPERATING EFFICIENCIES

Layered ravine disposal systems should provide a safe and hazard-free method of permanently storing spontaneously combustable waste materials. The material is a solid when desposed of, the problem is in rain leaching the waste that has been oxidized. The system will do little to eliminate the harsh chemicals that have been leached by the rain from the oxidized waste.

ENVIRONMENTAL PROBLEMS

The environmental problems of concern would involve leaching harsh chemicals in the wastes contaminating the groundwater or drainage systems below the ravine. Also fugitive dust while the waste is oxidizing. Once the ravine has been filled and allowed to weather for the proper time, a method for properly sealing and covering the wastes should be implemented.

NOTES

Refer to sections 4.3.2.1 and 4.3.2.6 for information concerning dams and levees.

MANUFACTURER / SUPPLIER

REFERENCES

1.) Mitchell, David R., and Leonard, Joseph W., et., Coal Preparation, AIME, New York, Second Edition, (1950): Third Edition (1968).

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Burial and Landfill
SPECIFIC DEVICE OR PROCESS Lined Burial Pits	**NUMBER** 4.3.2.4

POLLUTANTS CONTROLLED		**AIR**		**WATER**		**LAND**	
		GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
☐	**ORGANIC**	☐	☐	☐	☐	☐	☐
x	**INORGANIC**	☐	☐	☐	☐	☐	x Refuse, Ash
☐	**THERMAL**						
☐	**NOISE**						

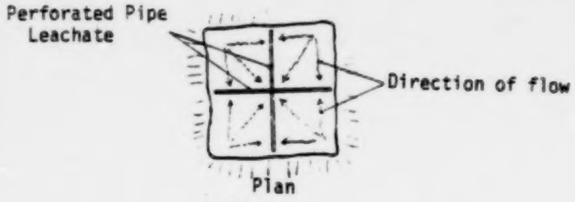


Figure 1

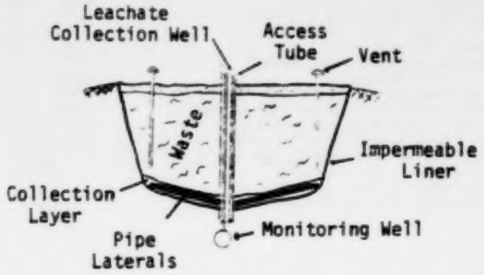


Figure 2

Process Description

When constructing a lined burial pit it is important that no groundwater contamination occurs. To prevent aquifer pollution, the bottom of the burial pit should be below the permanent groundwater table and be equipped with collection sumps so that the leachate fluids may be pumped out. By establishing the basin bottom below the water table the water flow gradient will be towards the collection sumps and not outward into the adjacent aquifers.

The pit liner must be impervious to prevent seepage of contaminants into the local groundwater system. Liners can be made of compacted soil clays, possolana, other forms of soil cement, and polymer membranes. Soil, clay, and cement liners provide an inexpensive and effective method of sealing the pit especially if the solid wastes contain water or exist in an arid climate. Soil base liners can crack and breakdown which could cause a serious leak into the surrounding area, if the wastes contained a large percentage of water.

Polymer membrane liners are expensive but provide a thin, flexible, and imprevious lining. The polymer liners must be covered with a fine textured material (1 to 2 ft min.) to prevent puncturing the lining during waste disposal. The type of lining used will depend on the waste material, climate, and groundwater conditions of the site. Refer to Section 4.1 (Pond Lining) for information concerning types and applications for the various membrane liners.

Perforated pipe laterals should be placed in the burial pit as shown in Figure 1. These laterals will provide leachate drainage to an access tube in the pit center where the fluid can then be pumped out. A monitoring well shown in Figure 2 should be installed below the pit to check for possible waste contamination of the surrounding area.

Vent pipes should be installed so as to allow waste gases to be vented into the atmosphere and not into the surrounding formations. The vents should not extend into the pipe lateral levels due to possible oxidation of the leachate which could cause precipitation of various compounds thus reducing the permeability of the leachate drain systems.

The design and construction must be done carefully to assure safe and efficient operation of the landfill system. The number and size of the burial pits will depend on the production of the plant and the method of disposal used.

Application Range

Lined burial pits are used when the waste material has a potential hazard of contaminating the local groundwater system. The lining will prevent any leachate solutions from entering the surrounding area. The lining material and the waste must be compatable so as to prevent the lining from breaking down. Refer to section 4.1 (Pond Lining) for application ranges for the specific liner to be used.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Capital costs[A] for the various burial pit liner materials are shown below. The costs are October, 1973 costs, and do not include contruction of subgrade nor the cost of the earth cover. These can range from $0.10 to $0.50/yd^2 per ft of depth. The cost for hot sprayed asphalt, however, does include the cost for the earth cover. Costs are shown as $/sq yd installed.

Material	Cost
Polyethylene (10 - 20 mils)	0.90 - 1.44
Polyvinyl chloride (10 - 30 mils)	1.17 - 2.16
Butyl rubber (31.3 - 62.5 mils)	3.25 - 4.00
Hypalon (20 - 45 mils)	2.88 - 3.06
Ethylene propylene diene monomer (31.3 - 62.5 mils)	2.43 - 3.42
Chlorinated polyethylene (20 - 30 mils)	2.43 - 3.24
Paving asphalt with sealer coat (2 inches)	1.20 - 1.70
Paving asphalt with sealer coat (4 inches)	2.35 - 3.25
Hot sprayed asphalt (1 gallon/yd^2)	1.50 - 2.00
Asphalt sprayed on polypropylene fabric (100 mils)	1.26 - 1.87
Soil-bentonite (9.1 lbs/yd^2)	0.72
Soil-bentonite (18.1 lbs/yd^2)	1.17
Soil-cement with sealer coat (6 inches)	1.25

OPERATING COSTS

The operating costs of concern would include pond, sump pump, vent, and monitor well maintenance costs; final waste containment costs; and recovered leachate disposal costs. In addition, leak detection equipment must be maintained and any major leak repaired. There are three methods for detecting leaks, groundwater monitoring wells, piping systems below the liner, and electrical sensing systems. The later is most effective for lined burial pits. Leaks, if they develop require major excavation to reach the liner, and may result in further damage to the liner.

OPERATING EFFICIENCIES

Lined burial pits provide an effective method to permanently dispose of solid wastes that contain leachable materials that may harm the environment. The system will do little to dispose of the harsh chemicals in the leachate. Methods of leachate disposal must therefore be implemented, or the burial pit must be covered with an impermeable membrane and sealed off from rain and groundwater contact. The permeability of the various liner materials are reported in Section 4.1.

ENVIRONMENTAL PROBLEMS

The environmental problem of concern would involve fugitive emissions of the leachate through lining cracks into the surrounding groundwater system. The use of the proper lining as well as an efficient pit maintenance program can prevent this problem from occurring.

NOTES

A) Capital Costs were reproduced from reference 2.

MANUFACTURER / SUPPLIER

See section 4.1 (Pond Lining) for manufacturers and suppliers.

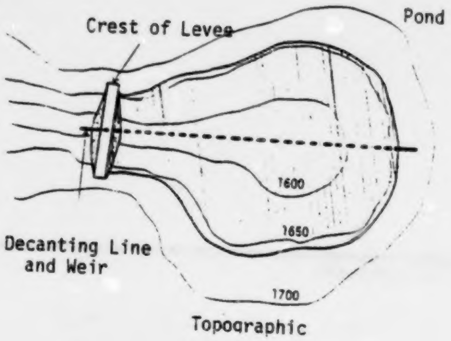
REFERENCES

1) Paroni, Joseph L., and Heer, John E., and Hagerty, Joseph D., Handbook of Solid Waste Disposal, Van Nostrand Reinhold, (1975), New York.

2) Geswein, Allen J., "Liners for Land Disposal Sites - An Assessment", EPA/530/SW-137, (March 1975).

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Burial and Landfill	
SPECIFIC DEVICE OR PROCESS Shallow Slurry Impoundment		**NUMBER** 4.3.2.6

POLLUTANTS CONTROLLED		**AIR**			**WATER**				**LAND**		
		GASES		**PARTICULATES**		**DISSOLVED**		**SUSPENDED**		**LEACHABLE**		**FUGITIVE**
☐	**ORGANIC**	☐		☐		☐		☐		☐		☐	
x	**INORGANIC**	☐		☐		☐		☐		☐		x	Refuse Ash
☐	**THERMAL**												
☐	**NOISE**												



Topographic

Figure 1.

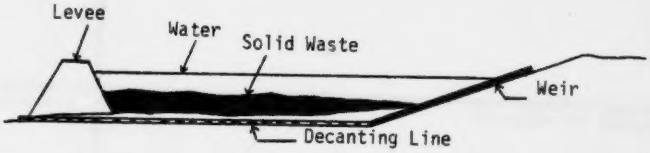


Figure 2.

Process Description

Shallow slurry impoundments involve large areas and shallow depths. The ponds are enclosed by low levees or ground irregularities. They are used where the terrain is level or gently rolling.

The shallow impoundments usually are at depths reaching a maximum of 60 feet. The area covered by these systems may exceed 200 acres. Soil and groundwater conditions must be studied to determine if any environmental problems exist. Pollution of groundwater and drainage systems, and the factors contributing to these problems must be taken into account when designing and constructing the impoundment.

Once planning begins, an inspection of the local topography, soils, rock strata, and the availability of proper levee building materials must be initiated. The climate and rainfall records of the area must be checked to find the frequency of cloudbursts or other weather irregularities that could possibly weaken, overflow or even cause the levee to fail. Spillways, drains or diversion ditches should be used to control floodwater problems if they are encountered. The levee should be located at the head of the valley so as to reduce the amount of natural drainage into the impoundment area. Levees may fail because of erosion at the top of the levee, lack of drainage under the levee or by using unstable building materials. Natural disasters such as earthquakes, major floods and etc. may of course cause levee failure and these factors should be taken into account before final design and erection.

The cross section shown in Figure 2 shows the basic components of a levee used for slurry impoundment. When the slurry enters the impoundment the solid fines settle out allowing the clear water to decant off. Note the decanting line and the weir which not only allow proper drainage under the levee but also enable the slurry water, once free of the suspended solids, to be released.

The safety of the people and the property in the drainage area below the levee must be of prime consideration before any planning or action takes place.

Application Range

Shallow slurry impoundment can be used in areas only after careful study has found them to be safe, stable, and relatively free of hazards which could cause levee failure. The fine refuse that is dumped into the impoundment should not be hazardous to the local groundwater system or to the surface environment.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Capital costs cannot be accurately displayed due to the many varying economic and labor factors involved in the construction of an impoundment system. It must be stressed that careful study and the use of the best building materials available be considered to assure proper construction of the levee. Capital costs should include, in addition to the construction costs, probable land costs, water rights, rights of way, land clearing, structure relocation costs (if any), engineering, and administration costs.

OPERATING COSTS

Because of widely varying economic and labor conditions in different localities it is not possible to furnish operating costs (if any). The operating costs of concern would include levee maintenance, dredging, decanting system maintenance, and final waste containment.

OPERATING EFFICIENCIES

If constructed properly the shallow slurry impoundment system should eliminate virtually all of the fine particulates in the slurry. The system will do little to eliminate harsh chemicals dissolved in the effluent.

ENVIRONMENTAL PROBLEMS

The environmental problem of conern would involve fugitive emissions of dissolved harsh chemicals in the slurry water contaminating the ground water or the drainage systems below the impoundment site. Once the slurry pond has filled with the settled fines a proper method of disposing of the solid refuse must be found and implemented.

NOTES

MANUFACTURER / SUPPLIER

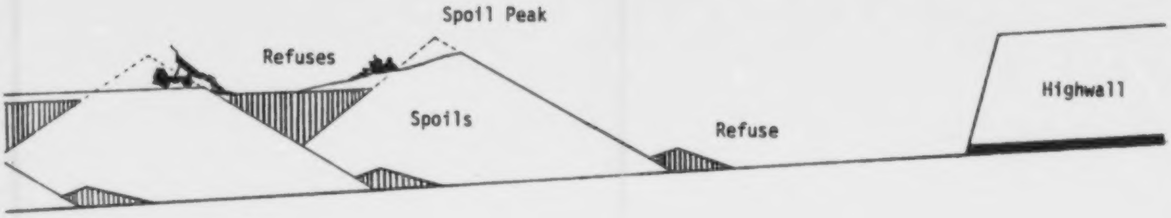
REFERENCES

1.) Mitchell, David R., and Leonard, Joseph W., ed., Coal Preparation, AIME, New York, Second Edition, (1950): Third Edition (1968).

2.) U.S. Bureau of Reclamation, Design of Small Dams, A Water Resource Publication, Second Edition, (1973), Revised Reprint, (1974).

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Burial and Landfill
SPECIFIC DEVICE OR PROCESS Strip Mine Disposal During Reclamation	**NUMBER** 4.3.2.7

	POLLUTANTS CONTROLLED	**AIR** GASES		**AIR** PARTICULATES		**WATER** DISSOLVED		**WATER** SUSPENDED		**LAND** LEACHABLE		**LAND** FUGITIVE
☐	**ORGANIC**	☐		☐		☐		☐		☐	☐	
X	**INORGANIC**	☐		☐		☐		☐		☐	x	Refuse, Ash
☐	**THERMAL**											
☐	**NOISE**											



Process Description

The disposal of solid wastes in strip mine spoils during reclamation is generally suited to most areas of the country where strip mining is carried out. Refuse is dumped into the valley formed between the spoil peaks by dump trucks, by conveyors, or by other forms of waste transportation as described in section 4.3.1. The adjacent spoil peaks are then dozed over the refuse and compacted. This method enables the solid wastes to be totally surrounded by cover material. The refuse also may be dumped along the toe of the spoils in the active pit.

At the end of the project mine life the haulage inclines and the final strip cut may be used for solid waste disposal. Strip mines have a distinct advantage over other surface disposal methods. The refuse is covered with material from adjacent spoil areas thus eliminating the need to compact and terrace the waste materials. This method not only reclaims the land (spoils, inclines, strip cuts, etc.) to state and federal standards but it also provides an excellent site for refuse disposal.

Strip mine disposal can also be modified to other landfill methods. The spoil valleys can be used for slurry impoundment, refuse stabilization, lined burial pits, etc.

Due to the fact that the mined land must be graded and reclaimed to legal standards, the incorporation of a waste disposal system into the spoil reclamation plan can be done easily and at very low cost.

Application Range

Strip mine disposal of refuse materials can be applied where ever strip mining is being practiced. Both solid and slurry wastes can be disposed of effectively.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

There will be little additional capital needed to incorporate a solid waste disposal system into a spoil reclamation plan. The capital required to transport the refuse to the disposal site will be covered in the Transportation section 4.3.1.

OPERATING COSTS

Because of mandatory reclamation laws, all spoil valleys, inclines, and final strip cuts must be reclaimed. Adding a solid waste disposal system to the reclamation plan would add very little additional costs to the dozing and grading. The only appreciable costs incurred would be in the transportation of the waste material to the disposal site. These costs are covered in the transportation section 4.3.1

OPERATING EFFICIENCIES

Land pollution and fugitive emissions are two problems of concern in dealing with the disposal of solid wastes. The strip mine landfill method is effective in reducing these problems. The efficiency of this reduction is not definable.

ENVIRONMENTAL PROBLEMS

This method reduces land pollution, but there may be problems in the following areas.

1) groundwater pollution from the leaching of refuse materials.

2) possible air pollution problems associated with spontaneous combustion of buried refuse piles.

NOTES

MANUFACTURER / SUPPLIER

REFERENCES

1) Staff, "Methods and Costs of Coal Refuse Disposal and Reclamation", U.S. Bureau of Mines Information Circular 8576, (1973).
2) Cheremisinoff, Paul N., and Yound, Richard A., ed. Pollution Engineering Practice Handbook, Ann Arbor Science Publishers, Michigan, (1976).
3) Leonard, Joseph W., and Mitchell, David R., ed. Coal Preparation, AIME, New York, Second Edition, (1950); Third Edition, (1968).

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Burial and Landfill
SPECIFIC DEVICE OR PROCESS Surface/Subsurface Distribution	**NUMBER** 4.3.2.8

POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
	GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
ORGANIC						
X **INORGANIC**						X Refuse, Ash
THERMAL						
NOISE						

PROCESS DESCRIPTION

Surface distribution of waste material into existing topsoil is an efficient and very economic method of disposing of wastes providing the refuse material has no harmful components which could be hazardous to the environment. The most common method involves digging small parallel trenches (2 feet deep) across the disposal area. Haul trucks and small front end loaders are used to haul and place the wastes into the trenches. A trencher is used to dig the trench rows. Once the waste has been placed in the trenches, the rows will be covered with ridges of topsoil on either side. By burying the wastes in this matter the refuse stabilization rates are increased while keeping dust control problems at a minimum. Cultivation of the area should begin after the refuse area has been allowed to dry out. Wet refuse that has been added to the soil creates moist and soft conditions which make the area difficult to cultivate. Once dry, the area can be cross-ripped, disked, leveled and seeded.

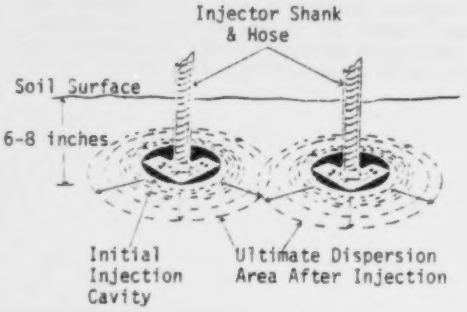


Figure 1. SUBSURFACE INJECTION PROCESS[4]

Subsurface injection is another type of surface distribution of wastes. Liquid wastes with up to 8% solids are carried by a tank, mounted on an all-terrian vehicle, equipped with injectors which by using low pressures injects the sludge into the soil at a depth of 6 to 8 inches, mixes with soil, and is covered all in one process. Briscoe Maphis has developed a system of continuous subsurface injection. The system utilizes a source of sludge; that is, sludge pumped from a treatment plant digester, holding tank, lagoon or mobile nurse tank via surface or underground pipelines to a flexible hose, hence the injector unit into the soil. The system is a complete closed loop with no exposure of sludge. Figure 1 illustrates. This method, as well as the trench method, virtually eliminates surface runoff and any odor problems. Subsurface injection involves liquefying the sludge (8% solids) so that it can be injected. The trench method handles the solid wastes directly.

Waste materials often contain compounds, pathogens and heavy metal concentrations that could be harmful to human, animal, and plant life. In addition, many of the substances could be leached into the groundwater systems. This means that the wastes that are to be disposed of should be carefully studied to assure that no harmful amounts of these substances occur. Dr. Shipp, an agronomist at Pennsylvania State University, has established guidelines to keep the soil below the danger level as far as the heavy metals are concerned. Zinc cannot exceed 15 ppm; copper, 750 ppm; lead, 500 ppm; chromium, 500 ppm; nickel, 150 ppm; and cadmium, 50 ppm. Pathogenic dangers do not extend more than 150 cm into the soil, nor last more than 2.5 months. Nitrogen leaching into the groundwater can also be a problem. With controlled techniques involving timing and balancing of climate and crop uptake with the disposal rates, most of these problems can be controlled.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

APPLICATION RANGE

Surface distribution of wastes introduces the refuse directly into the environment. Subsurface application eliminates or minimizes the items associated with surface distribution such as surface runoff, insect and rodent attraction, odors and visual pollution. As in any land application process, protection of the environment is essential and, therefore, adequate site design and operation must be provided for the protection of groundwater and soil if crops are included in immediate or future use of land.

CAPITAL COSTS

Capital costs cannot be accurately displayed due to the many varying economic and labor factors in the construction of permanent waste storage systems. Capital costs should include, in addition to the construction costs, probable land costs, water rights, right of way, land clearing, engineering, and administration costs. If a sub-surface injection system is used; a mobile injection unit plus all of its support equipment will have to be purchased.

It should be noted that land cost should only include interest or holding cost. The actual cost of the land should not be included in the capital cost of the system because a properly operated land application site is an appreciating asset.

OPERATING COSTS

Because of widely varying economic and labor conditions in different localities, it is impractical to furnish operating costs. The operating cost of concern would include site maintenance, transportation, injection and cropping.

OPERATING EFFICIENCIES

Surface disposal systems should provide a safe and hazard-free method of permanently storing waste materials. The waste materials of concern must be of a non-hazardous nature. The annual acreage requirements for soil enrichment are displayed by Figure 2. When the site is used for purely disposal purposes, significantly higher tonnages of wastes may be used.

Annual Acreage Requirements[4]

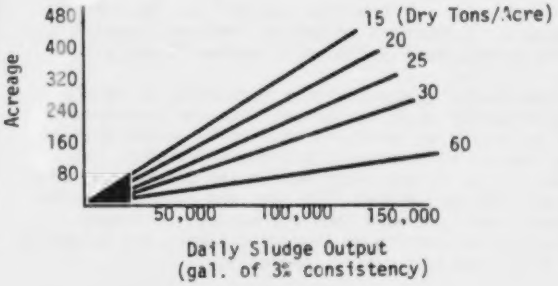


FIGURE 2

ENVIRONMENTAL PROBLEMS

The potential environmental impact of applying liquid waste to the land must be assessed to insure non-degradation of the environment (air, water or land).

NOTES

MANUFACTURER / SUPPLIER

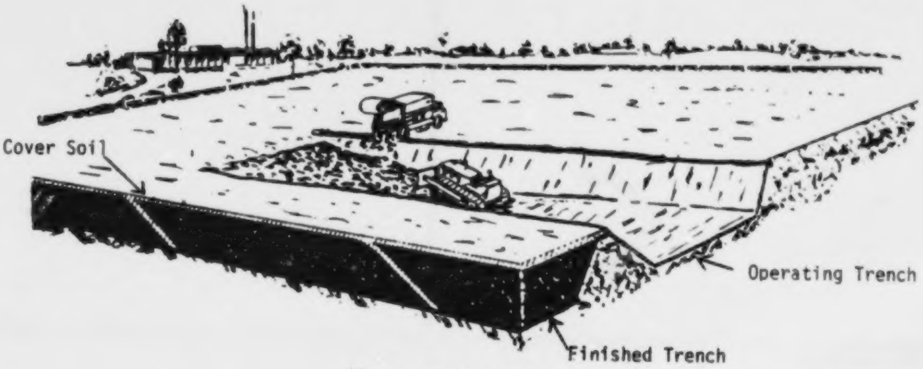
Ag-Chem Equipment Co., Inc.
Big Wheels, Inc.
Briscoe Maphis Environmental
Industrial & Municipal Engineering
Rickel Manufacturing Corporation

REFERENCES

1) Walker, J. M., et al, "Trench Incorporation of Sewage in Marginal Agricultural Land", EPA-600/2-75-034. (1975)
2) "Subsurface Application Solves Community's Sludge Disposal Problem", Public Works Magazine, December (1976).
3) Trout, T. J., Smith, J. L., and McWhorter, D. B., "Environmental Effects of Land Application of Anaerobically Digested Municipal Sewage Sludge", Transactions of the ASAE Vol. 19, No. 2 (1976).
4) "Sludge Management by Subsurface Injection", Bulletin, Briscoe Maphis, Inc., (1977).

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Burial and Landfill
SPECIFIC DEVICE OR PROCESS Trench Method	**NUMBER** 4.3.2.9

POLLUTANTS CONTROLLED	**AIR** GASES	**AIR** PARTICULATES	**WATER** DISSOLVED	**WATER** SUSPENDED	**LAND** LEACHABLE	**LAND** FUGITIVE
☐ ORGANIC	☐	☐	☐	☐		
☒ INORGANIC	☐	☐	☐	☐	☐	☒ Ash, Refuse
☐ THERMAL						
☐ NOISE						



(Courtesy of Office of Solid Waste Management Programs, U.S. Environmental Protection Agency)

PROCESS DESCRIPTION

The trench method is most suitable for sites where the water table is not near the surface, the land is gently sloping, and where there exists a deep layer of cover soil. The area should be acceptable for inexpensive excavation due to the tremendous amount of predevelopment work (trench digging) prior to any waste disposal.

This method of final disposal utilizes dozers and front end loaders to excavate long narrow trenches for disposal purposes. The cover soil removed from these excavations is either windrowed along the trench or it is stockpiled. The waste is then spread and compacted along the entire length of the trench. Once filled the trench is covered with a final layer of the stockpiled soil.

There are three basic trenching systems in practice today. One method is the "single progressive trench". This technique involves excavating a trench only far enough to create enough space to accomodate the daily refuse. As both cover material and additional dumping space are needed, the trench is continued. This progressive system is continued across the refuse area.

The second method, "the single trench", requires the entire trench be excavated with the cover material windrowed along the trench sides. The refuse is dumped and then covered with the windrowed material.

The third practice, "the dual trench", involves excavating two parallel trenches. The second trench is begun at least two feet away from the first. As this additional trench is excavated it provides cover material for the first. Once the first trench is full the second is nearing completion. A third parallel trench is then dug by the second and the process begins again. This excavate and cover cycle is continued across the entire disposal property.

The length and depth of the trench will vary from location to location, however the width is generally limited to about 1-1/2 times the width of the blade of the excavating equipment. The size of the disposal site will depend on the volume of waste to be handled, the method of trench disposal used, and the size of the equipment used to work the trenches.

APPLICATION RANGE

The trench method is most useful where the land is fairly level, a deep layer of topsoil exists, and where the water table is at a considerable depth below the trench depth. Due to the possibility of water perculating through the wastes it must be determined if the waste material to be disposed of contains any hazardous compounds which could harm the surrounding soil or the groundwater system below.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Capital costs cannot be accurately displayed due to the many varying economic and labor factors in the construction of permanent waste storage systems. Capital costs should include, in addition to the construction costs, probable land costs, water rights, rights of way, land clearing, engineering, and administration costs.

OPERATING COSTS

Because of widely varying economic and labor conditions in different localities, it is not possible to furnish operating costs (if any). The operating costs of concern would include site maintenance, waste spreading and compacting and final waste sealing and covering.

OPERATING EFFICIENCIES

Trench type disposal systems should provide a safe and hazard-free method of permanently storing waste materials. The material is a solid when disposed of, the problem is in rain leaching the waste that has been oxidized. The system will do little to eliminate the harsh chemicals that have been leached by the rain from the oxidized waste.

ENVIRONMENTAL PROBLEMS

The environmental problems of concern would include leached chemicals from the wastes contaminating the soil, groundwater, and drainage areas below the site; fugitive dust and wind-blown refuse may also cause problems if the disposal area is not properly maintained. Once the area has been filled a method for reclaiming the property should be implemented.

NOTES

MANUFACTURER/SUPPLIER

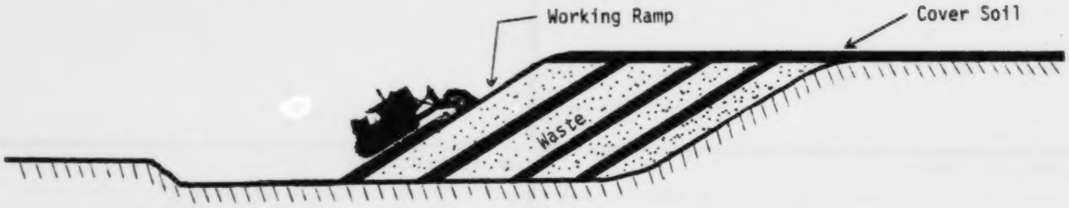
REFERENCES

1) Liptak, B. G., ed., Environmental Engineers Handbook - Volume 3 Land Pollution, Chilton Book Co., Radnor, PA., (1974).

2) International Harvestor, "Fill Methods For Sanitary Landfill", Waste Age, October, 1977.

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Burial and Landfill	
SPECIFIC DEVICE OR PROCESS Ramp Method		**NUMBER** 4.3.2.10

POLLUTANTS CONTROLLED		**AIR**		**WATER**		**LAND**	
		GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
	ORGANIC						
x	**INORGANIC**						x Ash, Refuse
	THERMAL						
	NOISE						



PROCESS DESCRIPTION

The "ramp method" or "progressive slope method" is considered to be one of the most efficient and economic methods of refuse disposal available because little advanced preparation or excavation work is required prior to the waste disposal operations. Cover material is handled only once which eliminates any soil rehandle costs.

The initial operation originates on an existing natural slope or depression. Before daily refuse deposition begins a small amount of topsoil is excavated in front of the working ramp and is stockpiled nearby. The waste material is then deposited at the base of the ramp, spread and compacted up against the slope by dozers or front end loaders, and then is covered by the previously stockpiled soil. For the most efficient operation of the land fill equipment, ramp slopes of no more than 30° should be used. At the end of the day the area should be clean, odorless, and free from disease carrying rodents.

The working ramp should be large enough to accomodate the daily tonnage of wastes to be handled and both the landfill equipment and waste hauling equipment. However, if the working area becomes excessive, problems with dust, odors, wind-blown refuse, and disease carrying rodents may occur.

APPLICATION RANGE

The ramp method can be used on existing ground surfaces by utilizing a natural slope or a side of a depression. Due to the possibility of water perculating through the wastes it must be determined if the waste material to be disposed of contains any hazardous compounds which could harm the surrounding soil or the groundwater system below. If possible a site with a water table level far below the surface level should be selected.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Capital costs cannot be accurately displayed due to the many varying economic and labor factors in the construction of permanent waste storage systems. Capital costs should include, in addition to the construction costs, probable land costs, water rights, rights of way, land clearing, engineering, and administration costs.

OPERATING COSTS

Because of widely varying economic and labor conditions in different localities, it is not possible to furnish operating costs (if any). The operating costs of concern would include site maintenance, waste spreading and compacting and final waste sealing and covering.

OPERATING EFFICIENCIES

Ramp disposal systems should provide a safe and hazard-free method of permanently storing waste materials. The material is a solid when disposed of, the problem is in rain leaching the waste that has been oxidized. The system will do little to eliminate the harsh chemicals that have been leached by the rain from the oxidized waste.

ENVIRONMENTAL PROBLEMS

The environmental problems of concern would include leached chemicals from the wastes contaminating the soil, groundwater, and drainage areas below the site; fugitive dust and wind-blown refuse may also cause problems if the disposal area is not properly maintained. Once the area has been filled a method for reclaiming the property should be implemented.

NOTES

MANUFACTURER / SUPPLIER

REFERENCES

1) Paroni, Joseph L., and Keer, John E., and Hagerty, Joseph D., Handbook of Solid Waste Disposal, Van Nostrand Reinhold, (1975), New York.

2) International Harvestor, "Fill Methods For Sanitary Landfill", Waste Age, October, 1977.

CLASSIFICATION Final Disposal	**GENERIC DEVICE OR PROCESS** Sealed Contained Storage (Permanent Storage)
SPECIFIC DEVICE OR PROCESS Underground Mines	**NUMBER** 4.4.3.1

POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
	GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
x **ORGANIC**					x	x
x **INORGANIC**					x	x
THERMAL						
NOISE						

Process Description

Underground mine openings are receiving more and more favorable attention for the permanent storage of ore processing tailings, hazardous wastes and even nuclear and chemical warfare wastes. Due to the stringent environmental regulations, safe and permanent methods of waste disposal have to be found. If used properly, underground mine openings can provide a reliable and permanent form of containment for waste materials.

To assure that the underground storage area is environmentally safe, certain criteria must be met. The area in and around the underground openings must be geologically stable, and the site must be hydraulically isolated to prevent surface and groundwater pollution. If the wastes are to be placed directly into the mine openings without any form of containment then the wastes must be chemically compatable with the surrounding host rock. If waste encapsulization is used then chemical compatability is not of great concern.

Various type of host rock that can be used for waste storage include: salt, potash, gypsum, limestone, shale, and in some cases granite. Salt is present throughout the United States and many mine openings exist for use in waste disposal. The potash deposits exist in the southwestern parts of the United States. However, the present mining techniques used for mining potash deposits make disposal in these areas difficult. Gypsum provides a good host rock but the mines are isolated and provide difficult access. If the conditions are dry, limestone will provide an excellent site. However, if the area is wet, limestone is a poor choice due to its solubility. Shales are wide spread and are very impervious to fluids, thus, providing a good site for waste disposal. Granite provides a strong and impervious environment for storage of refuse, however, granite can be fractured and faulted and therefore it should be examined closely before being used.

If the waste material of concern is mill or plant tailings, often time the wastes can be placed hydraulically as backfill in the mine openings. Hydraulic backfilling is the most common form of underground waste disposal. By filling the cavities with the tailings a natural roof support system is created thus reducing surface subsidence. Hazardous wastes may be encapsulized to help assure against waste migration into the surrounding rock. If needed, the underground opening can be reinforced and the host rock surface sealed to help provide a stable and impervious environment.

As the depth of the disposal area increases the accessibility decreases and the transportation costs increase. Therefore, most sites should be at a depth of less than 3,000 feet. The rock should have near horizontal bedding, and be easily accessible for transporting the wastes.

Application Range

Permanent storage of wastes underground can be used only where the underground openings meet the criteria mentioned in the "Process Description". Waste migration into the surrounding rock is of great concern, therefore this would be the major item to determine the site location and application.

If the wastes that are to be stored are flammable, explosive or emit gases, they should be given special consideration so as to assure that no damage to the surrounding environment will occur. Special encapsulization techniques may have to be used.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

OPERATING EFFICIENCIES

If done in a proper and responsible manner, the permanent storage of most waste materials in underground openings is safe and provides an effective solution to the waste disposal problems.

ENVIRONMENTAL PROBLEMS

If the wastes are stored improperly or are placed in an unstable environment, pollution of the ground water and host rock may occur.

NOTES

MANUFACTURER / SUPPLIER

REFERENCES

1.) Stone, Ronald B., et al, "Evaluation of Hazardous Wastes Emplacement In Mined Openings," PB-250 701, 1975.

2.) Williams, Roy E., Waste Production and Disposal in Mining, Milling and Metallurgical Industry, Miller Freeman Publications, Inc., 1975.

CLASSIFICATION Combustion Modifications	**GENERIC DEVICE OR PROCESS** Alternate Fuels (Synthetic Fuels)
SPECIFIC DEVICE OR PROCESS Low BTU Gas from Coal	**NUMBER** 6.3.3.1

	POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
		GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
x	**ORGANIC**	x	x				
x	**INORGANIC**	x	x				
	THERMAL						
	NOISE						

PROCESS DESCRIPTION

The gasification of coal to produce a clean low-BTU fuel gas may be considered as a pollution-reducing alternative to the direct combustion of coal. Fixed-bed (gravitating-bed) coal gas producers of about 10-ft diameter with a maximum cold gas production capacity of around 80 million BTU/hr are available from a number of manufacturers. A typical flow schematic, representing both one-stage and two-stage producers is shown in Figure 1. Low-BTU gas is produced by the partial combustion of coal with air and with the injection of steam. A typical gas composition and heating value are given in Table 1.

Coal is fed either continuously or periodically by gravity into the top of the producer. Air is blown in from the bottom, counter-current to the coal flow. Steam is introduced either in the air blast or through separate connections at the bottom. Ash falls through a grate and then, typically, through a water seal before discharge. A two-stage producer has two different gas draw-off points, with the top-gas circuit producing a relatively clean low-temperature gas stream which contains most of the coal volatiles.

The usual hot-gas cleanup sequence involves particulate removal in a hot cyclone, followed by a water quench, further cooling, and an electrostatic precipitator to remove tar oils. At this point the gas is free of particulates, tars and oils, and is suitable for direct use in many applications. If sulfur removal is required, a booster fan will provide the pressure necessary to feed the desulfurization system.

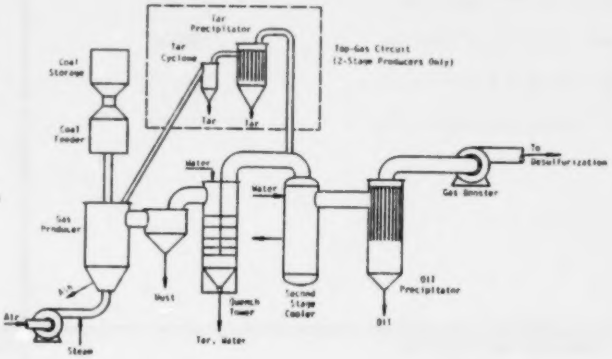


Figure 1. LOW-BTU GASIFICATION WITH GAS COOLING AND CLEANING.

TABLE 1. GAS PROPERTIES

Nitrogen, v%	48.7
Carbon Monoxide, v%	27.7
Hydrogen, v%	15.8
Carbon Dioxide, v%	4.1
Methane, v%	2.7
Hydrogen Sulfide, v%	0.6
Oxygen, v%	0.2
Non-Methane HC, v%	0.2
Molecular Weight,	24.2
HHV, BTU/SCF	175

Gas production rate and heating value are controlled by changing the coal and air feed rates. Responses to air rate are almost instantaneous, whereas responses to coal rate are very gradual. Most fixed bed producers can be operated at turndown ratios of four or five to one without a serious loss of efficiency, but at higher turndowns (lower output) the efficiency and the heating value of the product gas drops off drastically.

APPLICATION RANGE

Limited to coals with free swelling index of less than 2.5. Only limited amounts of coal fines can be tolerated.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	atm psi
VOLUMETRIC RATE	m³/s	10^4-10^5 ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	10^7-10^8 BTU/hr

CAPITAL COSTS

Approximate capital costs (1977) for a single coal gasifier installation (exclusive of desulfurization, if required) are:

Equipment	Cost
Gasifier	$600,000
Coal & Ash Handling	300,000
Water & Tar Handling	600,000
Gas Cleaning & Cooling	300,000
Building & Controls	700,000
TOTAL INSTALLED COST	$2,500,000

OPERATING COSTS

Operating manpower required can be highly variable depending on whether part-time help from adjoining operations is or is not available. Coal cost can be calculated from conversion efficiency. Other costs excluding depreciation and interest, could be as follows:

Insurance & Taxes	$125,000
Maintenance	87,500
Labor	93,600
Utilities	21,600
TOTAL YEARLY COST	$327,700

OPERATING EFFICIENCIES

The thermal efficiency for producing cold, clean (not desulfurized) low-BTU gas from coal will be approximately 75% for operation at 50-100% of gasifier design capacity. At lower rates the thermal efficiency can drop off sharply, because radiant heat losses remain constant.

ENVIRONMENTAL PROBLEMS

The major pollution problems with low-BTU gasifiers are involved with treatment of the quench water, and recovery and disposal of the coal tars, tar acids and tar oils

NOTES

MANUFACTURER / SUPPLIER

Applied Technology Corp.
Foster-Wheeler Energy Corp.
McDowell Wellman Engineering Corp.
Riley Stoker Corp.
Wilputte Corp.
Woodall-Duckham (USA), Ltd.
Pullman Swindell Division, Pullman, Inc.

REFERENCES

CLASSIFICATION

Fuel Cleaning

GENERIC DEVICE OR PROCESS

Physical Separation (Dense Media Separation)

SPECIFIC DEVICE OR PROCESS

Belknap Calcium Chloride Washer[A]

NUMBER

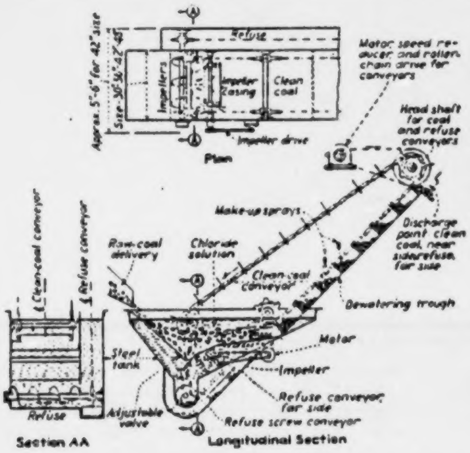
7.1.1.3

POLLUTANTS CONTROLLED	AIR GASES	AIR PARTICULATES	WATER DISSOLVED	WATER SUSPENDED	LAND LEACHABLE	LAND FUGITIVE
ORGANIC						
x INORGANIC	X SO_2					
THERMAL						
NOISE						

PROCESS DESCRIPTION[B]

Figure 1 shows a schematic diagram of the Belknap calcium chloride washer. Presized and prewetted raw coal enters at the surface of the washer solution and is separated according to the various specific gravities.[C] Refuse settles to the bottom and is removed by a screw conveyor running parallel to the refuse conveyor.[D] Solution within the washer is circulated by two opposing impellers.

The Belknap washer uses calcium chloride solutions ranging in specific gravity from 1.14 to 1.25. These solutions are circulated through the washer in an upward direction to produce an effective specific gravity of 1.40 to 1.60. Both flow and density are carefully controlled to provide the desired separation.



Refuse
Motor speed reducer and roller chain drive for conveyors
Approx. 5'-6" for 42" size
Size 30" 36" 42" 48"
Impellers
Impeller casing
Clean coal
Impeller drive
Plan
Head shaft for coal and refuse conveyors
Make-up sprays
Discharge point clean coal, near side refuse, far side
Clean-coal conveyor
Refuse conveyor
Raw-coal delivery
Chloride solution
Clean-coal conveyor
Dewatering trough
Steel tank
Motor
Impeller
Refuse conveyor, far side
Refuse screw conveyor
Refuse
Adjustable valve
Section AA
Longitudinal Section

Figure 1. THE BELKNAP CALCIUM CHLORIDE WASHER (1)

A second method which could be used to control the specific gravity within the washer is to wash the coal product with a calcium chloride solution to remove any suspended solids (slimes). This dense solution is then recycled to the washer to maintain the right specific gravity. In this case, the calcium chloride is used more as a stabilizing agent than the dense media itself. If the suspended solids from the washed coal product can be recycled back to the washer, the amount of calcium chloride required for density control can be reduced. In this way, the solids which naturally occur in the coal can be used to maintain the heavy density medium. Considerations of this type could improve the economics of this systems over other dense medium systems which utilize material from an outside source for density control, e. g. Magnetite Processes.

The washed coal product leaving the system has a considerable amount of entrained calcium chloride solution. This entrainment can reduce potential problems in coal dusting and freezing. The loss of calcium chloride, however, may limit the economic application of the process to coarser sizes of coal.

APPLICATION RANGE

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	20 °C	68 °F
PRESSURE	101.3 KPa	14.7 psi
VOLUMETRIC RATE	-- m³/s	-- ft³/min
MASS RATE	-- kg/s	-- lb/hr
ENERGY RATE	-- J/s	-- BTU/hr

The effective specific gravity within the washer can be adjusted from 1.40 to 1.60 by varying the solution density or recirculation rate. Consequently, the range of physical separation is limited to a specific gravity within this range.

Feed sizes can range from 8-in. (20.3 cm) to 3/8 in. (.95 cm), however, the feed to a single unit should not fluctuate very much. The size range that can be washed in a standard washer can be varied up to a 4:1 ratio, but should be limited to 3:1 or 2:1 if possible.

CAPITAL COSTS

OPERATING COST

OPERATING EFFICIENCIES

The recovery efficiency for coal coarser than 1/4-inch is 95 to 99% of the laboratory float sink tests. Trace elements association and removal characteristics for the physical separation of coal in general are shown in Table 1. The level of fluorine, which is present as part of the mineral apatite, would also be reduced. The chlorine and bromine contaminants (as well as the sodium and potassium associated with them) which are commonly present as the mineral halite would be removed along with other matter removed during coal benefication, (3).

Table 1. TRACE ELEMENT ASSOCIATION AND REMOVAL CHARACTERISTICS

Association	Trace Elements	Expected Removal
Organic	Ge, Be, B and U	None
More organic	P, Ga, Ti, V, and Sb	Small Amount
More mineral	Co, Ni, Cr, Se and Cu	Partial
Mineral	Hg, Zn, Cr, Cd, As, Pb, Mo, and Mn	Signficant

ENVIRONMENTAL PROBLEMS

Coal preparation reduces stack gas emissions but may also create pollution problems in the following areas.

1) land pollution created by refuse disposal.
2) water pollution from the leaching of oxidized refuse material.
3) air pollution from the spontaneous combustion of refuse piles.

NOTES

A) For other dense media separators, see all devices under 7.1.1 and 7.1.2.
B) Based on information from the Process Machinery Division of the Arthur G. McKee & Co., (reference 1)
C) This device can also be used in a secondary circuit to separate sink product from a primary separator into middlings and refuse.
D) Units can be designed with the separating compartment divided into two parallel sections. Each section would be equipped with individual medium circulation systems thus making it possible to wash a much wider range in one machine.

MANUFACTURER / SUPPLIER

ASV Engineering Ltd.
GEOMIN
Minerals Processing Co., Div. of Trojan Steel Co.
Process Machinery Division, Arthur G. McKee & Company

REFERENCES

1) Mitchell, David R., and Leonard, Joseph W., ed. Coal Preparation, AIME, New York, Second Edition, (1950); Third Edition, (1968).
2) Lowry, H. H., ed., Chemistry of Coal Utilization, John Wiley and Sons, New York, First Edition, (1945); Second Edition (1963).
3) Mezey, E. J., Singh, S., and Hissong, D. W., "Fuel Contaminants: Volume I, Chemistry " EPA 600/2-76-177a, (1976).

CLASSIFICATION Fuel Cleaning	**GENERIC DEVICE OR PROCESS** Physical Separation (Jigs)
SPECIFIC DEVICE OR PROCESS McNally Fine Coal Washer	**NUMBER** 7.1.3.8

POLLUTANTS CONTROLLED		**AIR**				**WATER**				**LAND**			
		GASES		**PARTICULATES**		**DISSOLVED**		**SUSPENDED**		**LEACHABLE**		**FUGITIVE**	
	ORGANIC												
x	**INORGANIC**	x	SO_2	x									
	THERMAL												
	NOISE												

PROCESS DESCRIPTION

The McNally Fine Coal Washer, shown in Figure 1, is a feldspar jig made up of three compartments each having one cell. The feldspar bed is supported on a screen with perforations smaller than the feldspar but larger than top size of the feed. The raw coal enters the first compartment and is separated from the refuse by the jigging action of the water transmitted through the feldspar bed. The refuse passes through the bed, and settles to the bottom of the hutch. The refuse from each hutch compartment can be removed from the jig by elevators, pumps or air lifts.

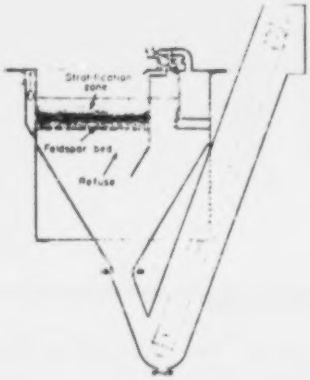


Figure 1. THE McNALLY FINE COAL WASHER

Each cell is completely independent of the others and is equipped with a sliding piston-type air valve. The exhaust-intake ratio can be varied to provide superior control of the jig. The impulse used in this jig is more intense than the one for the cleaning of coarse coal. The suction stroke is also very strong compared to coarse coal jigs. The automatic float, located in a separate compartment outside the jig bed itself, is designed to react to the liquid level. As refuse accumulates on the bed, the resistance to flow also increases and forces more water into the float compartment. An impedance-sensing device actuates the modulating air control valve to increase the intensity of the pulsion stroke. This intermittently distends the bed and allows the refuse to pass through. In this way the strength of each jig stroke is adjusted to give the desired separation, and to stablize the operation.

APPLICATION RANGE

The McNally Fine Coal Washer is designed to handle minus 1/2-inch coal. The standard unit has a capacity of 100 tons per hour. For the application ranges and limitations of jigs in general, see Device 7.1.3.7.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

OPERATING EFFICIENCIES

This jig has been tested using 1/4 in x 48 mesh coal containing 29 percent ash. The overall efficiency was shown to be 97 percent and produced a clean coal with 11 percent ash. The reject had an ash content of 69 percent. The clean coal yield was 69 percent.

For the removal efficiencies of trace elements by washing processes in general, see the Belknap calcium chloride washer, Device 7.1.1.3.

ENVIRONMENTAL PROBLEMS

NOTES

A) For additional jigs, see all other devices listed in this section (7.3.1).

MANUFACTURER / SUPPLIER

McNally-Pittsburg Manufacturing Corp.

REFERENCES

1) Mitchell, David R., and Leonard, Joseph W., ed, Coal Preparation, AIME, New York, Third Edition (1968).

CLASSIFICATION Fuel Cleaning	GENERIC DEVICE OR PROCESS Physical Separation (Jigs)
SPECIFIC DEVICE OR PROCESS McNally-Pittsburg Norton Standard Washer[A]	NUMBER 7.1.3.10

POLLUTANTS CONTROLLED	AIR		WATER		LAND	
	GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
ORGANIC						
X INORGANIC	X SO_2					
THERMAL						
NOISE						

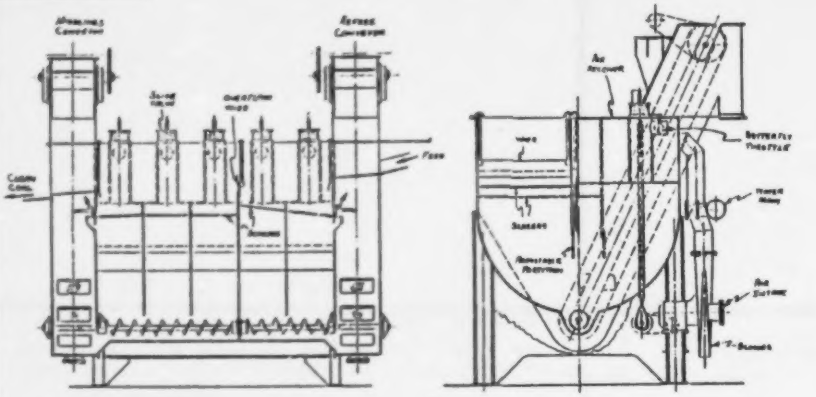


Figure 1. THE McNALLY-PITTSBURG NORTON WASHER (1)

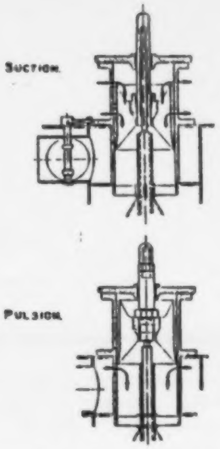


Figure 2. SLIDE VALVE

PROCESS DESCRIPTION

Figure 1 shows a schematic diagram of the McNally-Pittsburg Norton Washer. This washer is a Baum type jig and has a similar operation to the Link-Belt Air Pulsated Wash Box (Device 7.1.3.7). Presized and prewetted raw coal enters the refuse compartment from the right. The heavy refuse is separated from the coal by the jigging action of the washer. Refuse settles and the partially cleaned coal flows over a weir into a second wider compartment where the middlings are separated in a similar manner.

Refuse and middlings settle onto sloped screens and are withdrawn automatically as the levels increase. A number of finger-like gates across the width of the screen hold the bed in place and are raised to remove the material as required. After the refuse and middlings are released, they settle to the bottom of the hutch and are removed by separate conveyor systems. In this model the refuse flows counter the flow of the coal, similar to the Link-Belt model. This facilitates the removal of the heaviest refuse first and does not require the movement of this refuse along the full lendth of the screen. McNally, however, does supply a model where the refuse and coal flow in parallel. The operation of this device is discussed under Device 7.1.3.9.

Air pressure for the pulsion stroke is supplied by an integral blower pressurizing a receiver built into the body of the jig itself. The slide valve located partially within the receiver operates on the same principle as the piston valve in the Link-Belt washer. Air enteres through a throttle valve which controls the flow into the jig cell, and is exhausted out the top section on the suction stroke. Figure 2 shows a schematic diagram of the slide valve. The McNally-Pittsburg Norton washer has an adjustable partition dividing the hutch. This partition can be raised or lowered during operation to give an uniform distribution to the water rising from the hutch.

APPLICATION RANGE, LIMITATIONS

The application ranges given for jigs in general under the Link-Belt air pulsated wash box, Device 7.1.3.7, also apply in this case.

OPERATING RANGES	METRIC (SI)		ENGLISH	
TEMPERATURE	20	°C	68	°F
PRESSURE	101.3	KPa	14.7	psi
VOLUMETRIC RATE	--	m³/s	--	ft³/min
MASS RATE	125	kg/s	992,250	lb/hr
ENERGY RATE	--	J/s	--	BTU/hr

CAPITAL COSTS

OPERATING COST

The service requirements for the McNally Norton jig, based on 100 ton/hr of 3" top size feed, are listed below. (3)

Power Requirement - 0.35 hp/ton of coal
Water Requirement - 4.2 tons of water/ton of coal (1700 gpm)

OPERATING EFFICIENCIES

For removal efficiencies of trace elements by washing processes in general, see the Belknap calcium chloride washer, Device 7.1.1.3.

ENVIRONMENTAL PROBLEMS

Coal preparation reduces stack gas emissions but may also create pollution problems in the following areas.

1) land pollution created by refuse disposal.
2) water pollution from the leaching of oxidized refuse material.
3) air pollution from the spontaneous combustion of refuse piles.

NOTES

A) For additional jigs, see all devices listed in this section 7.1.3.

MANUFACTURER / SUPPLIER

McNally-Pittsburg Manufacturing Corp.

REFERENCES

1) Lotz, C. W., "Notes on the Cleaning of Bituminous Coal", West Virginia University, (1960), 561 pp.
2) Mitchell, David R., and Leonard, Joseph W., ed, Coal Preparation, AIME, New York, Third Edition, (1968).
3) Yancy, H. F., and Geer, M. R., "Performance of a Baum-Type Coal-Washing Jig," U.S. Bureau of Mines Report of Investigations 3371, (1938).

CLASSIFICATION Fuel Cleaning	**GENERIC DEVICE OR PROCESS** Fuel Gas Treatment (Absorption)
SPECIFIC DEVICE OR PROCESS Adip Process	**NUMBER** 7.5.1.3

POLLUTANTS CONTROLLED		AIR		WATER		LAND	
		GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
X	**ORGANIC**	X CO_2, COS					
X	**INORGANIC**	X H_2S					
	THERMAL						
	NOISE						

PROCESS DESCRIPTION

The Adip process is shown schematically in Figure 1. The sour feed gas enters the bottom of the absorber where it flows countercurrent to an aqueous solution of DIPA (di-isopropanolamine) which chemically removes H_2S, COS and CO_2 present in the gas. The purified gas exits the top of the absorber.

The rich solution flows from the bottom of the absorber and is intercharged with the hot lean solution before entering the top of the stripper. In the stripper the rich solution flows countercurrent to rising steam generated in the reboiler. As a result of the heating, the absorption reactions are reversed and the regenerated acid gases flow overhead with the steam. The overhead steam from the stripper flows through a condenser and reflux vessel where the steam is condensed and separated from the acid gases. The resulting acid gas stream is usually sent to a sulfur recovery unit.

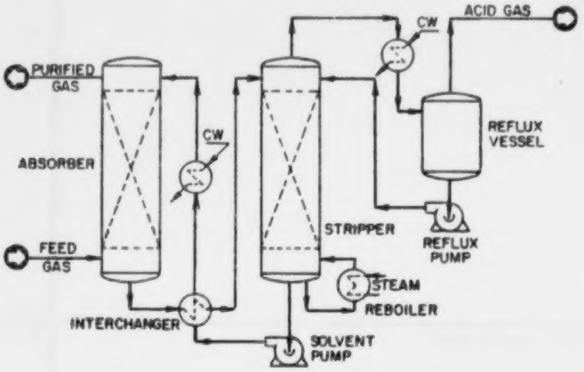


Figure 1. Adip Process Flow Diagram

The hot lean solution is pumped from the bottom of the absorber and cooled by interchange with the cool rich solution. It then flows through a water-cooled exchanger and returns to the top of the absorber.

The absorption reactions of H_2S and CO_2 with DIPA are as follows:

$$R_2NH + H_2S \rightarrow R_2NH_2 \,.\, HS$$

$$R_2NH + CO_2 + H_2O \rightarrow R_2NH_2 \,.\, HCO_3$$

In the above reactions DIPA is represented by R_2NH. DIPA reacts with COS to form thiocarbonates.

APPLICATION RANGE

The absorber operates in the 100 to 140°F temperature range and at pressures from 0 to 1000 psig. The regenerator usually operates at temperatures in the range of 250-275°F and at presure near atmospheric.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	38-60 °C	100-140 °F
PRESSURE	0-6,900 KPa	0-1000 psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

Typical utility requirements per MMSCF when treating gas containing 10% H_2S and 2.5% CO_2 at 250 psig, with 2ppm H_2S and 0.2% CO_2 in the purified gas are as follows:[A]

Steam, lb	22,100
Electric Power, KWH	85

OPERATING EFFICIENCIES

The H_2S content in natural gas can be lowered to 5ppm, in fuel gas to 100ppm and in LPG to 10ppm. Selective removal of H_2S, CO_2, COS can be achieved by proper selection of operating pressure, DIPA concentration, flow rates etc., to suit the feed gas.

ENVIRONMENTAL PROBLEMS

The acid gas stream requires further processing in a sulfur recovery unit such as a Claus unit to remove H_2S and COS.

NOTES

A. From reference 1.

MANUFACTURER / SUPPLIER

Shell Development Company

REFERENCES

1. Dravo Corp., "Handbook of Gasifiers and Gas Treatment Systems," ERDA Report FE-1772-11 (February 1976).

2. Riesenfeld, Fred, and Kohl, A., Gas Purification, Gulf Publishing Co. (2nd Edition 1974).

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Fuel Cleaning	Fuel Gas Treatment (Absorption)

SPECIFIC DEVICE OR PROCESS	NUMBER
Alkacid (Alkazid) Process	7.5.1.4

POLLUTANTS CONTROLLED	AIR		WATER		LAND	
	GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
x ORGANIC	x CO_2					
x INORGANIC	x H_2S					
THERMAL						
NOISE						

PROCESS DESCRIPTION

The Alkacid process is shown in Figure 1. The sour feed gas enters the bottom of the absorber and flows countercurrent to the Alkacid solution which absorbs H_2S and CO_2 from the feed gas. The purfied gas exits the top of the absorber. The rich solution is pumped from the bottom of the absorber to the top of the stripper where the absorption reactions are reversed. The regenerated acid gases exit the top of the stripper where the contained steam is condensed and separated from the acid gases before they are sent to a sulfur recovery unit. The hot lean solvent from the bottom of the stripper is cooled by both interchange with the cool rich solvent and water before being returned to the top of the absorber. Two types of a absorbents are used in the process: Alkacid "M" which is an aqueous solution of a potassium salt of methy-amino-propionic acid and; Alkacid "DIK" which is a potassium salt of dimethyl-amino-acetic acid. The DIK solution is a more selective absorbent of H_2S in the presence of CO_2, CS_2 and/or HCN.

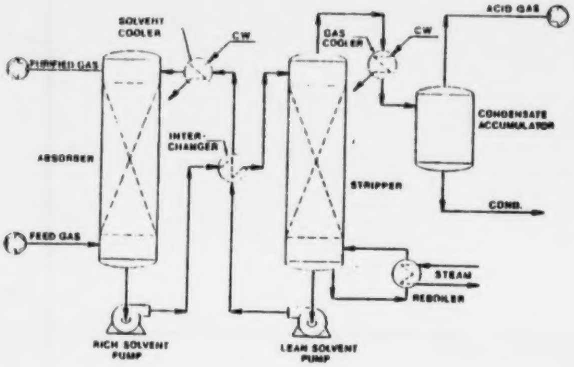


Figure 1. FLOW DIAGRAM FOR ALKACID PROCESS

APPLICATION RANGE

The absorber normally operates at temperatures near ambient and pressure from 0-1000 psig. The stripper is usually operated at about 5 psig.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	23 °C	75 °F
PRESSURE	0-6,900 KPa	0-1000 psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

Typical operating requirements for a feed gas containing 0.7% H_2S and 30% CO_2 are:[A]

Steam, lb/MMSCF	15,500
Cooling Water, gal/MMSCF	93,500
Electricity KWH/MMSCF	230

Operating pressure was 1100 psig and operating temperature was 77°F. The purified gas contained 5 ppm H_2S.

Solution losses are limited to mechanical leakage and degradation due to the presence of HCN or O_2 in the feed gas.

OPERATING EFFICIENCIES

A purfied gas containing less than 5 ppm H_2S can be produced. Solution loss is minimal; however, some degradation of the solution will occur if HCN or O_2 is present in the feed gas.

ENVIRONMENTAL PROBLEMS

The regenerated acid gas stream requires further treatment in a sulfur recovery unit. Degraded solution will also have to be disposed; however, this loss is minimal.

NOTES

A. From reference 3.

MANUFACTURER / SUPPLIER

Davy Powergas, Inc.

REFERENCES

1. Hydrogen Processing, "Gas Processing Handbook Issue" April 1975.

2. Riesenfeld, Fred and Kohl, Arthur, Gas Purification, Gulf Publishing Co., Houston (2nd Edition 1974).

3. Dravo Corp., "Handbook of Gasifiers and Gas Treatment Systems," ERDA Report FE-1772-11 (February 1976).

CLASSIFICATION Fuel Cleaning	**GENERIC DEVICE OR PROCESS** Fuel Gas Treatment (Absorption)
SPECIFIC DEVICE OR PROCESS Benfield Process	**NUMBER** 7.5.1.21

POLLUTANTS CONTROLLED		**AIR**				**WATER**				**LAND**			
		GASES			**PARTICULATES**		**DISSOLVED**		**SUSPENDED**		**LEACHABLE**		**FUGITIVE**
x	**ORGANIC**	x	CO_2, COS										
x	**INORGANIC**	x	H_2S										
	THERMAL												
	NOISE												

PROCESS DESCRIPTION

The Benfield hot potassium carbonate process was developed by Benson, Field and coworkers at the U.S. Bureau of Mines. The process has been widely used for scrubbing carbon dioxide, hydrogen sulfide, and other pollutants from industrial gases at moderate to high pressure. The basic flow sheet is shown in Figure 1. Gas to be purified is introduced into an absorber below a packed section - stream 1. The gas flows upward through the packed bed and is contacted with an activated[A] Benfield solution (hot potassium carbonate). Purified gas leaves at the top of the absorber - stream 2. The rich solution from the bottom of the absorber is regenerated while passing downward through the second tower (stripper). Process steam and/or reboiler vapors are used as the stripping media. Both the absorber and regenerator (stripper) operate at a temperature of about 230°F. The cooled acid gases are removed at the top of the separator - stream 3.

There is provision for blowdown between the regenerator and the bottom of the reboiler - stream 4.

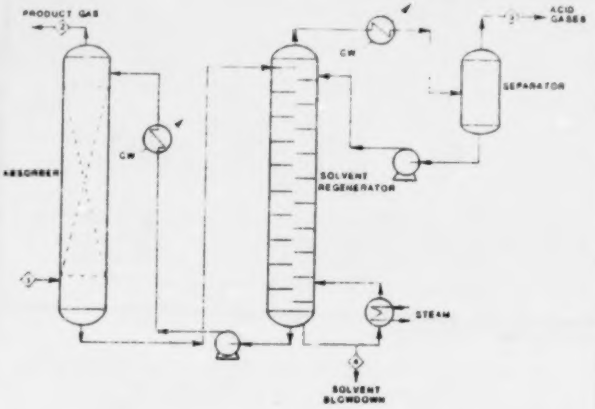


Figure 1. TYPICAL FLOW DIAGRAM - BENFIELD ACID GAS REMOVAL PROCESS

The chemical reactions for hydrogen sulfide and carbon dioxide removal can be represented as:

$$K_2CO_3 + H_2S \rightleftharpoons KHCO_3 + KHS$$
$$K_2CO_3 + CO_2 + H_2O \rightleftharpoons 2KHCO_3$$

Equilibrium pressures (H_2S and CO_2) over the solution increase with temperature and concentration of KHS and $KHCO_3$. Since $KHCO_3$ is formed during absorption of H_2S and CO_2, the acid gas equilibrium pressures and the $KHCO_3$ concentration are interdependent and must be carefully evaluated in designing the process. When the carbon dioxide to hydrogen sulfide ratio of the feed gas is greater than 8, a reasonable estimate of capital cost and utility requirements can be made by assuming total acid gas to be only CO_2.

Typical trace components removed from coal derived gases are carbonyl sulfide, carbon disulfide, thiophene[B], mercaptans, ammonia, and hydrocyanic acid. Generally no reaction is expected with hydrocarbons. For additional information on trace components see note C.

There are two variations of the basic process described below: (1) In a single stage, split stream arrangement, most of the regenerated solution enters at an intermediate point in the absorber. The remainder of the solution is cooled and fed to the top of the absorber. This yields a higher degree of purification because of the lower equilibrium pressure of carbon dioxide and hydrogen sulfide over the cooled solution, (2) In the Benfield HiPure process, there are two independent countercurrent circuits using multiple effects of stripping steam. There is bulk removal of CO_2 and H_2S in the first stage of the absorber. The second stage provides final purification to reduce the sulfur concentration of the product gas to a ppm level.

APPLICATION RANGE

By appropriate selection of design criteria, carbonyl sulfide, hydrogen sulfide, and carbon dioxide can be removed to ppm levels from H_2S concentrations as high as 10% and CO_2 concentration as high as 25 - 45%. The practical limit of operating temperature is visualized as 280°F for economical operations. The operating pressures range from 100 to 2000 psia. A normal set of operating parameters is 250°F (121°C) and 615 psia (4200 KPa). The concentrations of potassium carbonate used in the process are discussed in detail in Reference 1. See "Operating Costs" for volumetric, mass, and energy rates.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	138 °C	280 °F
PRESSURE	690-13,300 KPa	100/2000 psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

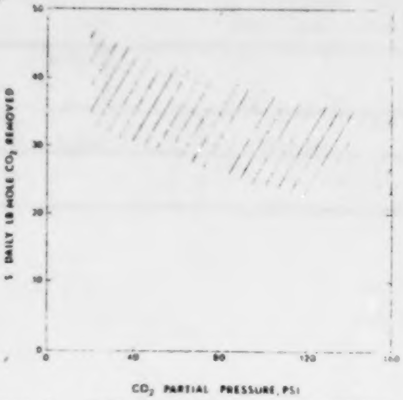


Figure 2. TYPICAL COSTS OF BENFIELD HOT POTASSIUM CARBONATE OR HiPURE PROCESSES

These costs should be considered as rough approximations for battery limits installations. Costs do not include some utility items (for example, steam and electric generating equipment). See Reference 4.

OPERATING COSTS

Typical utility requirements for the activated Benfield process per MMSCF of feed gas at 250°F and 615 psig containing about 1.5% H_2S and 5.4% CO_2, with 2 ppm H_2S and 0.01% CO_2 in the purified gas, are as follows:

Steam @ 50 psig, saturated, lb/MMSCF	15,700
Cooling Water, Gal/MMSCF	30,000*
Electric Power, KWH/MMSCF	138
Benfield Solution	N.A.

Typical utility requirements for the activated Benfield process per MMSCF of feed gas at 250°F and 615 psig containing about 45% CO_2, with 0.1% CO_2, in the purified gas are as follows[2]:

Steam @ 50 psig, saturated, lb/MMSCF	38,200
Cooling Water, Gal/MMSCF	30,000*
Electric Power, KWH/MMSCF	735
Benfield Solution	N.A.

*Based on acid gas leaving the condenser at 200°F.

See Reference 2 for additional information.

OPERATING EFFICIENCIES

The process efficiencies for typical H_2S bearing gas and CO_2 bearing gas can be found in the section "Operating Costs" along with utility requirements.

ENVIRONMENTAL PROBLEMS

Acid gases leaving the stripper require further processing in a sulfur recovery unit such as a Claus, Stretford, or others.

NOTES

A) Research by the Benfield Corporation has improved the hot carbonate process as developed by the Bureau of Mines. The addition of small quantities of other components (activators) has minimized corrosion, increased the reaction rate, and altered equilibria relationship.
B) The process is not guaranteed for removal of thiophene. Its absorption has not been proven with duplicate results in any commercial unit (1975).
C) Trace components are covered in a paper by R. W. Parrish and H.B. Nelson, 167th. National Meeting of the American Chemical Society, Los Angeles, CA.

MANUFACTURER / SUPPLIER

Benfield Corporation

REFERENCES

1) Riesenfeld, Fred and Kohl, Arthur, Gas Purification, Gulf Pub. Co., Houston 2nd Ed., 1974.
2) Dravo Corp., "Handbook of Gasifiers and Gas Treatment Systems", ERDA, FE-1772-11, February 1976.
3) Hydrocarbon Processing, "Gas Processing Handbook Issue" April 1975.
4) McCrea, D. H., and Field, J. H., "Applicability and Econ. of Benfield Process" Paper 29b, AIChE 78 Nat'l Meet.
5) Parrish, R. W., and Field, J. H., "The Ben. Proc. in Coal Gas.", 24th Gas Cond. Conf., U. of Ok., March 1974.

CLASSIFICATION Fuel Cleaning	**GENERIC DEVICE OR PROCESS** Fuel Gas Treatment (Absorption)	
SPECIFIC DEVICE OR PROCESS MDEA Process		**NUMBER** 7.5.1.27

POLLUTANTS CONTROLLED		**AIR**				**WATER**				**LAND**			
		GASES		**PARTICULATES**		**DISSOLVED**		**SUSPENDED**		**LEACHABLE**		**FUGITIVE**	
x	**ORGANIC**	x	CO_2, CS_2, COS										
x	**INORGANIC**	x	H_2S										
	THERMAL												
	NOISE												

PROCESS DESCRIPTION

The MDEA process is a chemical absorption process which uses an aqueous solution of methyl diethanolamine (MDEA) as the absorption medium. Typical concentration of MDEA in the aqueous solution is 30-50 wt %. The primary reactions for removal of H_2S and CO_2 are as follows:

$$R_2NCH_3 + H_2S \rightleftharpoons R_2NHCH_3 \cdot HS$$

$$R_2NCH_3 + CO_2 + H_2O \rightleftharpoons R_2NHCH_3 \cdot HCO_3$$

In the above reactions MDEA is represented by R_2NCH_3. The acid gases are absorbed by the above reactions in the absorber, and when heat is applied in the stripper, the reactions are reversed liberating the acid gases.

The MDEA process is shown schematically in Figure 1. The sour feed gas enters the bottom of the absorber and passes countercurrent to the aqueous solution of MDEA which enters the top. The MDEA solution chemically absorbs H_2S, CO_2 and other acid gases. The rich MDEA solution from the bottom of the absorber is then heated by interchange with hot lean solution and flows to the stripper for regeneration.

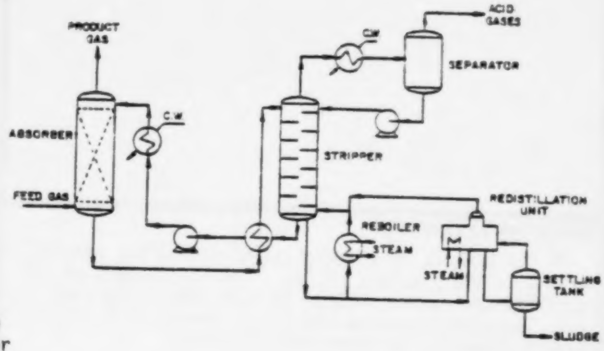


Figure 1. FLOW DIAGRAM FOR MDEA PROCESS

In the stripper the absorption reactions are reversed with heat supplied by stripping steam generated in the reboiler. The steam and released acid gases pass overhead where the steam is condensed, separated from the acid gases and refluxed to the stripper, while the acid gas steam goes to a sulfur recovery unit.

The hot lean solution is pumped from the bottom of the stripper and cooled by interchange with the cool rich solution and with cooling water before being returned to the top of the absorber.

A portion of the hot lean MDEA solution is withdrawn from the bottom of the stripper and sent to a redistillation unit. The spent amines, degraded by reactions with HCN or organic acid are recovered by distillation at higher temperatures and returned together with makeup solution to the stripper. Unrecovered amines form a sludge which is pumped to a settling tank and then to disposal.

APPLICATION RANGE

Absorber temperatures usually are in the range of 80° to 125°F, the stripper from 240° to 250°F, and the redistillation unit from 250° to 300°F. In order to maintain the reactions and operating temperature limits the feed gas should be in the range of 60° to 120°F.

Pressure in the absorber can vary from 0 to 1000 psig. The stripper and redistillation unit usually operate at lower pressures in the range of 7-10 psig.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	27-52 °C	80-125 °F
PRESSURE	0-6,900 KPa	0-1000 psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

Typical utility requirements per MMSCF of feed gas at 105°F and 60 psig containing 0.6% H_2S and 10% CO_2 as listed below for the two different purified gas specifications[A].

Product Gas Concentrations	50 ppm H_2S, 3.3% CO_2	965 ppm H_2S 7.3% CO_2
Steam lb/MMSCF	10,700	5,000
Cooling water	N.A.	N.A.
Electric Power KWH/MMSCF	15	8
Solvent Loss, lb/MMSCF	0.5	0.5

OPERATING EFFICIENCIES

The process is somewhat selective in its removal of H_2S in the presence of CO_2. The H_2S content in the purified gas can be reduced to less than 4 ppm even at very low pressures with CO_2 being removed to a lesser extent depending on operating conditions.

ENVIRONMENTAL PROBLEMS

The acid gases require further treatment in a sulfur recovery unit such as a Claus or Stretford. The amine sludges generated in the process also require disposal.

NOTES

A. From reference 3.

MANUFACTURER / SUPPLIER

Dow Chemical Company

REFERENCES

1. Hydrogen Processing, "Gas Processing Handbook Issue" April 1975.
2. Riesenfeld, Fred and Kohl, Arthur, Gas Purification, Gulf Publishing Co., Houston (2nd Edition 1974).
3. Dravo Corp., "Handbook of Gasifiers and Gas Treatment Systems," ERDA Report FE-1772-11 (February 1976).

CLASSIFICATION Fuel Cleaning	**GENERIC DEVICE OR PROCESS** Fuel Gas Treatment (Absorption)	
SPECIFIC DEVICE OR PROCESS Purisol Process		**NUMBER** 7.5.1.29

POLLUTANTS CONTROLLED	**AIR** GASES	**AIR** PARTICULATES	**WATER** DISSOLVED	**WATER** SUSPENDED	**LAND** LEACHABLE	**LAND** FUGITIVE
☒ **ORGANIC**	☒ CO_2	☐	☐	☐	☐	☐
☒ **INORGANIC**	☒ H_2S	☐	☐	☐	☐	☐
☐ **THERMAL**						
☐ **NOISE**						

PROCESS DESCRIPTION

The Purisol process uses N-Methyl-2-Pyrrolidone (NMP) to physically absorb acid gases. The process is shown schematically in Figure 1. The sour gas enters the absorber where it is dehydrated with rich NMP and then scrubbed with regenerated NMP. The NMP physically absorbs CO_2, H_2S and some hydrocarbons. Any entrained NMP is removed by a water wash before the treated gas exits the top of the absorber.

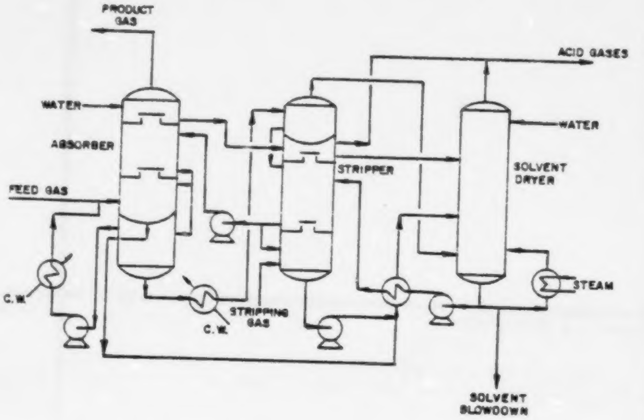


Figure 1. PURISOL PROCESS FLOW DIAGRAM

The rich solvent is flashed at relatively high pressure in the lower section of the absorber where the absorbed hydrocarbons and part of the acid gas are separated and recycled to the feed gas stream. The rich solvent, containing the the absorbed acid gases, is then cooled and regenerated in the stripping column by two-stage flashing to atmospheric pressure. The H_2S and part of the CO_2 are separated in the first flash and flow to the solvent dryer. The remaining CO_2 is separated from the NMP in the second stage by countercurrent stripping with air or nitrogen. The lean solvent from the second stage is then pumped to the absorber. The NMP/water mixtures from the dehydration sections of the absorber and stripper are combined and sent to the solvent dryer. Off gas from the first stripper stage and wash water from the absorber are also feed to the dryer where the water and acid gases are separated from the NMP by distillation. Water saturated acid gas exits the top of the dryer and is sent to a sulfer recovery unit, while the dehydrated NMP returns to the stripper.

APPLICATION RANGE

The Purisol solvent, NMP, has a high solubility for hydrogen sulfide, therefore, it is particularily suited to selectively absorb hydrogen sulfide in the presence of carbon dioxide. Typical operating temperatures for the absorber and regenerator are from 85-105°F. The pressure in the absorber can be operated from very low pressure up to 1000 psig depending on the feed and product gas requirements

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	29-40 °C	85-105 °F
PRESSURE	6900 KPa	1000 psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

Typical utility requirements per MMSCF of feed gas as listed below. The feed gas contained 6% H_2S and 15% CO_2 at 1070 psig and the product gas contained 2 ppm H_2S and 13.6% CO_2[A].

Steam, lb.	3,125
Cooling Water, gal.	13,300
Electricity, KWH	264
NMP Loss, lb.	2.1

OPERATING EFFICIENCIES

The process can reduce H_2S concentrations to less than 2 ppm and CO_2 to less than 10 ppm.

ENVIRONMENTAL PROBLEMS

The acid gas stream produced by the process requires further treatment in a sulfur recovery unit such as a Claus unit.

NOTES

A. From reference 3

MANUFACTURER / SUPPLIER

American Lurgi Corporation

REFERENCES

1.) Hydrogen Processing, "Gas Processing Handbook Issue" April 1975.

2.) Riesenfeld, Fred and Kohl, Arthur, Gas Purification, Gulf Publishing Co., Houston (2nd Edition 1974).

3.) Dravo Corp., "Handbook of Gasifiers and Gas Treatment Systems," ERDA Report FE-1772-11,(February 1976).

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Fuel Cleaning	Fuel Gas Treatment (Absorption)

SPECIFIC DEVICE OR PROCESS	NUMBER
Rectisol Process	7.5.1.30

POLLUTANTS CONTROLLED		AIR				WATER				LAND			
		GASES		PARTICULATES		DISSOLVED		SUSPENDED		LEACHABLE		FUGITIVE	
x	ORGANIC	x	HCN, Sulfur, CO_2										
x	INORGANIC	x	H_2S.										
	THERMAL												
	NOISE												

PROCESS DESCRIPTION

The basic flow diagram for the Rectisol process is shown in Figure 1 for treatment of a synthesis gas. Inlet gas enters the bottom of the two-stage absorber which operates at elevated pressures of 300 to 1,000 psia. The gas is washed countercurrently with -100°F methanol, which is fed to the middle of the absorber; practically all the H_2S and any heavy hydrocarbons, and the bulk of the CO_2 and organic sulfur compounds are removed in this stage. The temperature of the methanol increases due to the heat of absorption, until it reaches about -4°F at the absorber outlet.

The methanol is regenerated by two successive pressure reductions and flashing of the dissolved gases. In the first to about - 30°F, and in the second step in which the pressure is lowered to 3 psia, the temperature of the methanol is reduced to -100°F. The cooled regenerated solvent which still contains some CO_2 is recycled into the middle of the absorption column.

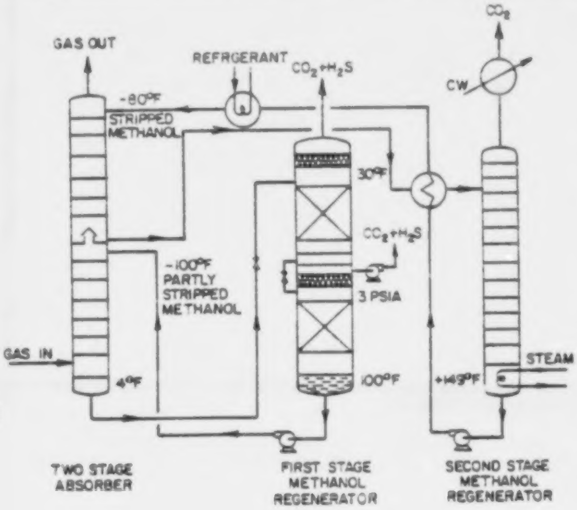


Figure 1. SCHEMATIC FLOW DIAGRAM OF BASIC RECTISOL PROCESS

The partially purified gas leaving the lower section of the absorber flows to the second treating stage, where it is washed countercurrently with a small stream of thoroughly stripped methanol which enters the column at about -80°F. In the operation most of the remaining CO_2 and potentially all of the residual organic sulfur compounds are removed from the gas.

The rich solvent is withdrawn at the bottom of the second contacting stage, stripped of acid gas by heating with indirect steam in a conventional stripping column, cooled, and recycled into the top of the contactor.

The basic flow scheme may be modified in various ways: precooling of the feed gas by heat exchange with the purified gas, successive flashing at three different pressure levels with recycle of the gases disengaged in the first stage to the absorber inlet, regeneration by using inert stripping gas such as N_2, and regeneration at elevated temperatures.

APPLICATION RANGE

High pressures favor operation of this physical absorption process, so the normal operating range is 300 - 2,000 psig. Absorber temperatures are typically in the range of -100 to 0°F and temperatures in the regenerators are up to 150°F. Commercial applications include purifying low Btu gas, carbon dioxide removal and drying of ammonia synthesis gas and feed gas to an LNG plant. By proper selection of the processing scheme, operating temperature, pressure, and solvent rate, the process can be adjusted to selectively remove H_2S and CO_2 separately.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	-73 to -17°C	-100 to 0°F
PRESSURE	2,000-14,000 kPa	300-2,000 psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Capital costs not available.

OPERATING COSTS

Typical requirements[A], per MM SCF of gas processed, when processing a feed gas containing 1% H_2S and COS and 5-6% CO_2 initially, and 35% CO_2 after shift at 685 psig are given below. The purified gas contains <0.1 ppm H_2S and COS, and 0.1% CO_2.

Steam, lb/MM SCF	2,550
Cooling Water, Gal/MM SCF	121,000
Electric Power, KWH/MM SCF	550
Solvent Loss, lb/MM SCF	40
Waste Heat for Refrigeration MM BTU/MM SCF	11
Stripping Gas (N_2), SCF/MM SCF	77,000

OPERATING EFFICIENCIES

The process generally can produce a product gas with sulfur and carbon dioxide concentrations of less than 1 ppmv.

ENVIRONMENTAL PROBLEMS

The offgases from the regenerators contain high concentrations of H_2S and COS and will need to be treated in a sulfur recovery plant such as a Claus. In some variations of the basic flow sheet both a lean and a rich H_2S flash gas is produced. The lean H_2S gas would then need to be processed in a Stretford and/or a tail gas treating process. A process condensate may also be produced in the process and would require treatment to remove any phenols, cyanides, ammonia, hydrocarbon, etc., it may contain.

NOTES

A) Operating requirements were reproduced from reference 1.

MANUFACTURER / SUPPLIER

American Lurgi Corporation

REFERENCES

1) Dravo Corporation, "Handbook of Gasifiers and Gas Treatment Systems", ERDA Report FE-1772-11, (Feb. 1976).
2) Riesenfeld, Fred and Kohl, Arthur, Gas Purification, Gulf Publishing Co., Houston (2nd Ed. 1974).
3) Cavanaugh, E. C., et al, "Environmental Assessment Data Base For Low/Medium - BTU Gasification Technology", Radian Corporation, EPA Report 600/7-77-125, (November 1977).

CLASSIFICATION
Fuel Cleaning

GENERIC DEVICE OR PROCESS
Fuel Gas Treatment (Absorption)

SPECIFIC DEVICE OR PROCESS
Selexol Process

NUMBER
7.5.1.37

POLLUTANTS CONTROLLED		AIR			WATER				LAND			
		GASES		PARTICULATES		DISSOLVED		SUSPENDED		LEACHABLE		FUGITIVE
X	ORGANIC	x	Sulfur, CO_2									
x	INORGANIC	x	Sulfur,									
	THERMAL											
	NOISE											

PROCESS DESCRIPTION

Figure 1 is a flowsheet of the Selexol process treating a feed gas containing light hydrocarbons. Sour feed gas enters the bottom of the absorber while the stripped and semi-stripped solvent enters the top. The solvent physically absorbs the H_2S and some of the CO_2, COS and mercaptans as it passes countercurrent to the gas. The purified gas exits the top of the absorber and the rich solvent exits the bottom and passes successively through a power recovery turbine to a high pressure flash tank, intermediate pressure flash tank and a low pressure flash tank. At this point a portion of the partially stripped solvent is pumped back to the absorber with the remainder feed to the stripper to remove remaining acid gases. The stripping gas containing acid gases is combined with the low pressure flash acid gases for further treatment downstream to remove the sulfur compounds. The high pressure flash gas is recycled to the absorber to increase the solvent selectivity for sulfur compounds.

The number of stages for flashing depends on the specific application. For example synthesis gas from a coal gasifier would normally require only one stage of flashing before stripping.

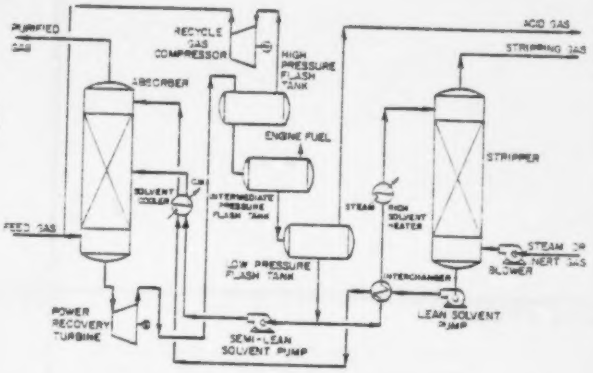

PURIFIED GAS
RECYCLE GAS COMPRESSOR
HIGH PRESSURE FLASH TANK
ABSORBER
ACID GAS
STRIPPING GAS
ENGINE FUEL
STRIPPER
SOLVENT COOLER
CW
INTERMEDIATE PRESSURE FLASH TANK
STEAM
RICH SOLVENT HEATER
FEED GAS
LOW PRESSURE FLASH TANK
STEAM OR INERT GAS
BLOWER
INTERCHANGER
POWER RECOVERY TURBINE
LEAN SOLVENT PUMP
SEMI-LEAN SOLVENT PUMP

Figure 1. Selexol Process Flow Diagram

APPLICATION RANGE

The absorber normally operates in the range of 500-1000 psig as high pressures favor the physical absorption process. The absorber operating temperature range is 20-100°F. Applications for the process include sour natural gas, synthesis gases and refinery gases.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	-7-37 °C	20-100 °F
PRESSURE	3450-6900 KPa	500-1000 psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

Typical utility requirements[A] per million SCF when treating a gas containg about 1/2% H_2S and 35% CO_2 at 500 psig, with <0.1 ppm H_2S and 11% CO_2 in the purified gas, are estimated to be:

Steam, lb/MM SCF	3,000
Cooling Water, Gal/MM SCF	35,000
Electric Power, KWH/MM SCF	900
Solvent Loss, lb/MM SCF	0.5

In this example, the acid gas is removed after shift in two stages: the H_2S is removed first and then the CO_2.

OPERATING EFFICIENCIES

The Selexol process can reduce the concentration of H_2S, COS and mercaptans to less than 1 ppm. The CO_2 can be retained or reduced to any desired level. Selexol's different solvent loading for H_2S and CO_2, combined with optional recycle, allow the process to be adjusted to meet specific feed and product gas specifications, including selective absorption of the sulfur compounds.

ENVIRONMENTAL PROBLEMS

The acid gas and stripping gas streams require further processing in a sulfur recovery unit, such as a Claus Plant.

NOTES

A) Operating requirements were reproduced from Reference 1.

MANUFACTURER / SUPPLIER

Allied Chemical Corporation

REFERENCES

1) Dravo Corporation, "Handbook of Gasifiers and Gas Treatment Systems", ERDA Report FE-1772011, (Feb. 1976).
2) Riesenfeld, Fred and Kohl, Arthur, Gas Purification, Gulf Publishing Co., Houston (2nd Ed. 1974).
3) Cavanaugh, E. C., et al, "Environmental Assessment Data Base for Low/Medium - BTU Gasification Technology", Radian Corporation, EPA Report 600/7-77-125, (November 1977).
4) Hydrocarbon Process, "Gas Processing Handbook", (April 1975 issue).

CLASSIFICATION
Fuel Cleaning

GENERIC DEVICE OR PROCESS
Absorption

SPECIFIC DEVICE OR PROCESS
Sulfiban Process

NUMBER
7.5.1.41

POLLUTANTS CONTROLLED	AIR: GASES	AIR: PARTICULATES	WATER: DISSOLVED	WATER: SUSPENDED	LAND: LEACHABLE	LAND: FUGITIVE
x ORGANIC	x CO_2					
x INORGANIC	x H_2S					
THERMAL						
NOISE						

PROCESS DESCRITPION

The Sulfiban process, utilizes an aqueous solution of mono-ethanolamine (MEA) to remove hydrogen sulfide (H_2S) and other acidic components from industrial gases. To minimize MEA degradation and prevent corrosion, certain inhibitors are added to the solution. The process is used for refinery gas, coke oven gas, synthesis gas, natural gas and hydrogen in hundreds of plants. The process is shown in Figure 1. Feed gas enters at the bottom of the absorber, and the clean gas exits at the top of the absorber. Rich solution containing acid gases is pumped from the absorber and heated by the lean solution going to the absorber. The rich solution passes downward in the MEA stripper where steam removes the acid gases. The stripper overhead stream is cooled to remove the condensate and allow the acid gases to separate out in a knockout drum. Solution is withdrawn from the stripper bottom and fed to a redistillation unit. Here the spent amines, degraded by reactions with HCN and O_2 and/or organic sulfides, are recovered by distillation at higher temperatures. Unrecovered amines form a sludge which is pumped to a settling tank and sent to disposal. Recovered amines are returned to the stripper. The hot lean solution is pumped from the stripper bottom and cooled by interchange with the cool rich solution. It is then further cooled in a water cooled exchanger and returned to the absorber.

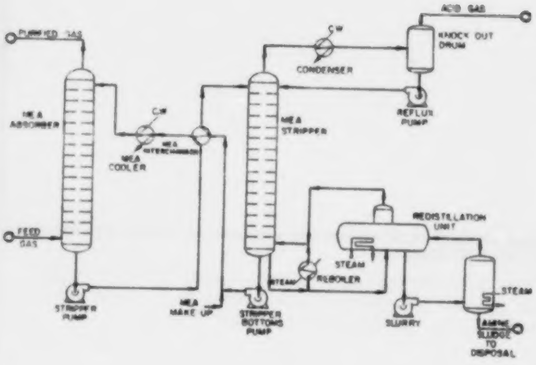

PURIFIED GAS
ACID GAS
CW
KNOCK OUT DRUM
CONDENSER
REFLUX PUMP
MEA ABSORBER
CW
MEA INTERCHANGER
MEA COOLER
MEA STRIPPER
REDISTILLATION UNIT
FEED GAS
STEAM
STEAM
REBOILER
STEAM
STRIPPER PUMP
MEA MAKE UP
STRIPPER BOTTOMS PUMP
SLURRY
AMINE SLUDGE TO DISPOSAL

Figure 1. Sulfiban Process Flow Diagram

The acid gas stream usually is processed further to produce elemental sulfur by a modified Claus process or used to produce sulfuric acid.

APPLICATION RANGE

The temperature in the stripper is usually 100°F, the stripper 200-250°F, and the redistillation unit 250-300°F. The absorber will operate over a pressure range from 0 to 1000 psig.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	38 °C	100 °F
PRESSURE	6,900 KPa	1000 psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

Typical utility requirements per MM SCF of feed gas at 40 psig. containing about 1.7% H_2S, 9.7% CO_2, 20 ppm HCN, and 300 ppm COS, are estimated to be as follows.[A] The purified gas contains 2 ppm H_2S, a negligible amount of HCN, and CO_2 and COS in ppm level.

Steam, lb/MM SCF	49,000
Cooling Water, gal/MM SCF	161,000
Electric Power, KWH/MM SCF	50
Solvent (MEA) Loss, lb/MM SCF	1.6

Above feed and purified gas concentrations are for a typical coal gasification application. In the case of a coke oven gas application, the H_2S and CO_2 concentrations are lower, the purified gas requirements are less stringent, and therefore the utility requirements are lower. The Sulfiban process can be used for either application, but requires certain design considerations for each application.

OPERATING EFFICIENCIES

The H_2S and HCN concentrations of a typical gas stream can be reduced by more than 90%. The process can reduce the H_2S content to about 1 ppm.

ENVIRONMENTAL PROBLEMS

The acid gas stream requires further processing in a sulfur recovery unit such as a Claus plant. The amine sludge generated in the process also requires disposal.

NOTES

A. From reference 2.

MANUFACTURER / SUPPLIER

Black, Sivalls and Bryson, Inc.

REFERENCES

1. Riesenfeld, Fred and Kohl, Arthur, Gas Purification, Gulf Publishing Co., Houston, (2nd Edition 1974).

2. Drave Corp., "Handbook of Gasifiers and Gas Treatment Systems", ERDA (February 1976).

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Fuel Cleaning	Fuel Gas Treatment (Absorption)

SPECIFIC DEVICE OR PROCESS	NUMBER
Sulfinol Process	7.5.1.42

POLLUTANTS CONTROLLED	AIR		WATER		LAND	
	GASES	PARTICULATES	DISSOLVED	SUSPENDED	LEACHABLE	FUGITIVE
☒ ORGANIC	☒ CO_2, COS					
☒ INORGANIC	☒ H_2S					
☐ THERMAL						
☐ NOISE						

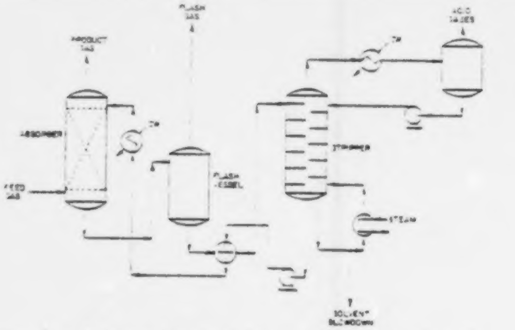


Figure 1. Typical Flowsheet for Sulfinol Process

PROCESS DESCRIPTION

The Sulfinol process uses a mixture of a physical and chemical solvent as the absorption medium. The solvent consists of an ethanolamine, usually di-isopropanolamine (DIPA), sulfolane (tetrahydrothiophene dioxide), and water. The process will remove H_2S, CO_2, COS and mercaptans.

A typical flowsheet of the Sulfinol process is shown in Figure 1. The feed gas enters the bottom of the absorber and flows countercurrent to the solvent. The purified gas exists at the top of the absorber.

The rich solution, containing the absorbed acid gases and hydrocarbon flows from the bottom of the absorber to an intermediate pressure flash vessel to recover any hydrocarbons and prevent subsequent problems during sulfur recovery of the acid gases. The flash gas is either recycled to the absorber or used as plant fuel.

After flashing, the solution passes through a heat exchanger where it is heated with hot lean solvent from the stripper. In the stripper, the absorption reactions are reversed with heat supplied by stripping steam generated in the boiler. The regenerated acid gases pass overhead with the steam, which is then condensed, separated from the acid gases and refluxed to the stripper. The acid gases are then sent to a sulfur recovery unit such as a Claus or Stretford.

Hot lean solvent is pumped from the bottom of the stripper, and passed through the lean/rich solution heat exchanger. It is then cooled further in a water or air cooled exchanger and returned to the top of the absorber.

The absorption/regeneration reactions of H_2S and CO_2 with DIPA can be expressed as follows:

$$R_2NH + H_2S \rightleftharpoons R_2NH_2 . HS$$

$$R_2NH + CO2 + H2O \rightleftharpoons R_2NH_2 . HCO_3$$

In the above equation R_2NH is DIPA.

APPLICATION RANGE

The pressure in the absorber can vary from atmospheric to 1000 psi with the higher pressures favoring the physical absorption. The stripper generally operates near atmospheric pressure. The lean solvent temperature entering the stripper is typically in the range of 100-125°F. The process has been adapted to process feed gases containing from 0 to 53% H_2S and from 1.1 to 46% CO_2.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	38-52 °C	100-125 °F
PRESSURE	100-6,900 KPa	15-1,000 psi
VOLUMETRIC RATE	m³/s	ft³/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

Typical requirements for utilities, per pound of acid gas removed, are:[A]

Electricity, kwh	<0.01
Low pressure steam, lb	0.8-1.6
Cooling water, gal.	5.4-9.8

OPERATING EFFICIENCIES

The Sulfinol process can reduce acid gas concentrations to the following levels:

H_2S	<0.25 grain/100 scf
CO_2	<0.3 mole %
Mercaptons	<0.2 grain/100 scf
Total sulfur	<1 grain/100 scf

ENVIRONMENTAL PROBLEMS

The acid gases require further treatment in a sulfur recovery unit such as a Claus or Stretford. The amine sludges generated in the process also require disposal.

NOTES

A. From reference 1

MANUFACTURER / SUPPLIER

Shell Development Company

REFERENCES

1.) Hydrocarbon Processing, "Gas Prosessing Handbook Issue" April 1975.
2.) Riesenfeld, Fred and Kohl, Arthur, Gas Purification, Gulf Publishing Co., Houston (2nd Edition 1974).
3.) Dravo Corporation, "Handbook of Gasifiers and Gas Treatment Systems," ERDA Report FE-1772-11, (February 1976).

CLASSIFICATION Fuel Cleaning	**GENERIC DEVICE OR PROCESS** Fuel Gas Treatment (Absorption)
SPECIFIC DEVICE OR PROCESS Vacuum Carbonate Process	**NUMBER** 7.5.1.45

POLLUTANTS CONTROLLED		AIR GASES	AIR PARTICULATES	WATER DISSOLVED	WATER SUSPENDED	LAND LEACHABLE	LAND FUGITIVE
X	ORGANIC	x HCN, CO_2					
X	INORGANIC	x H_2S					
☐	THERMAL						
☐	NOISE						

PROCESS DESCRIPTION

A simplified flow diagram of the Vacuum Carbonate process is shown in Figure 1. The feed gas is contacted with dilute sodium carbonate in the countercurrent flow absorber, and the purified gas exits the top of the absorber. The rich solution from the bottom of the absorber passes to the top of the actifier, where it is regenerated by vacuum distillation. The regenerated solution is then pumped through a solution cooler before entering the top of the absorber. Acid gases from the top of the actifier may consist of H_2S, HCN, CO_2 and water vapor and passes through a condenser and then a vacuum pump system. This acid gas stream requires further treatment in a sulfur removal plant.

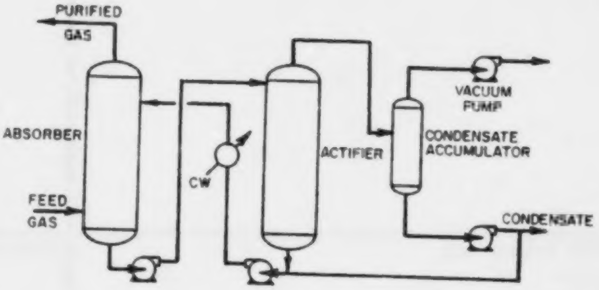


Figure 1. Vacuum Carbonate Process

The primary reactions occurring in the process are:

$$Na_2CO_3 + CO_2 + H_2O \longrightarrow 2NaHCO_3$$

$$Na_2CO_3 + H_2S \longrightarrow NaHS + NaHCO_3$$

$$Na_2CO_3 + HCN \longrightarrow NaCN + NaHCO_3$$

The heat required for activation of the solution is normally supplied by low pressure steam in a reboiler at the base of the actifier. A modification of the process utilizes low-level waste heat.

APPLICATION RANGE

The absorber is generally operated at pressure below 25 psig and the actifier at 2.0 to 2.5 psig. The absorber operates at ambient temperature while the actifier operates at 140°F.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	22 °C	75 °F
PRESSURE	175 KPa	25 psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

OPERATING COSTS

Typical utility requirements for a plant processing 55 MMSCFD of gas containing 500 grains of H_2S per 100 cu. feet and 40 grains of HCN per 100 cu. feet with 90% H_2S removal and 85% HCN removal are as follows:

Water	1,273,600 gallons/day
Electricity	7,879 KWH/day
Steam	9,600 lb/day
Sodium Carbonate	400 lb/day

OPERATING EFFICIENCIES

Removal efficiencies of up to 93% for H_2S and 90% for HCN have been reported.

ENVIRONMENTAL PROBLEMS

The acid gas stream requires further treatment in a sulfur recovery unit. The spent solution must be disposed of after 6 to 8 months operation.

NOTES

MANUFACTURER / SUPPLIER

Kopper Company, Inc.

REFERENCES

Kohl and Riesenfeld, Gas Purification, Gulf Publishing Co. (Second Edition, 1974).

CLASSIFICATION Fuel Cleaning	**GENERIC DEVICE OR PROCESS** Fuel Gas Treatment (Dry Oxidation)
SPECIFIC DEVICE OR PROCESS Conventional - Box Fe_2O_3 Purifier	**NUMBER** 7.5.2.2

POLLUTANTS CONTROLLED		**AIR**		**WATER**		**LAND**	
		GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
	ORGANIC						
X	**INORGANIC**	X H_2S					
	THERMAL						
	NOISE						

PROCESS DESCRIPTION

Feed gas is passed through a bed of hydrated ferric oxide and H_2S present in the feed gas is removed by the following reaction: $2\ Fe_2O_3 + 6\ H_2S \rightarrow 2\ Fe_2S_3 + 6\ H_2O$. The ferric sulfide is then oxidized by air yielding elemental sulfur and ferric oxide by the reaction: $2\ Fe_2S_3 + 3O_2 \rightarrow 2\ Fe_2O_3 + 6S$. The process is shown schematically in Figure 1.

The regeneration of the ferric sulfide can be done either continuously by injecting air into the feed gas stream as in Figure 1 or intermittently by shutting off the feed gas and recirculating gas containing a small amount of air. The regeneration can be done until the surface area of the iron oxide particles become covered with elemental sulfur resulting in loss of activity and excessive bed pressure drops.

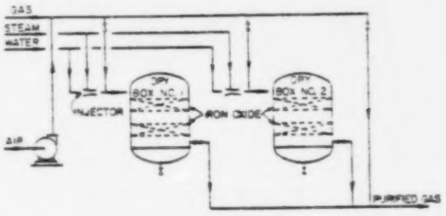


Figure 1. SCHEMATIC FLOW DIAGRAM OF BASIC IRON OXIDE PURIFICATION PROCESS.

Spent sorbent is then removed from the bed and usually discarded, but the sulfur may be recovered if it is economical. In some instances it is burned to form SO_2 which is then used to manufacture sulfuric acid, or recovered by solvent extraction.

Either mixed or unmixed iron oxides can be used in the process. Mixed oxides are prepared by supporting finely divided ferric oxide on materials with large surface area and loose texture such as wood shavings and granulated or crushed slag. The mixed oxides have the advantage of being able to control the bulk density, iron oxide content, moisture content and pH more accurately.

Unmixed oxides are prepared from iron ore or metallic iron and contain approximately 75 percent ferric oxide, 10 percent water, and 15 percent impurities.

APPLICATION RANGE

Early installations operated at near atmospheric pressure, but in recent years, plants in the 6 to 20 million SCFD range are operating at pressure of 100 to 325 psig. Operating temperatures are in the range of 80 to 120°F. The process generally operates on gases containing 10 to 75 grains of H_2S/100 SCF gas (160 to 1200 ppm) but have been used for gases containing up to 1000 grains H_2S/100 SCF (1.6 vol. %). Because of the requirement to dispose of the spent iron oxide the process is generally used for H_2S removal on a small scale.

OPERATING RANGES	**METRIC (SI)**	**ENGLISH**
TEMPERATURE	27-49 °C	80-120 °F
PRESSURE	104-2243 KPa	15-325 psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Capital costs not available.

OPERATING COSTS

Utility requirements for the process are quite small. Electricity is required for operating the air blower and a small amount of water is required to keep the bed moist. Cost of iron sponge is $2/bushel in 1977 dollars. There are periodic labor requirements for unloading, loading and disposing of spent iron oxide.

OPERATING EFFICIENCIES

Purification to H_2S levels of less than 1 ppm is possible. Approximately 5,000 bushels of iron sponge are required per 1 million SCFD of feed gas. One bushel can absorb approximately 6 pounds of sulfur before being discarded.

ENVIRONMENTAL PROBLEMS

The spent iron oxide or sponge must be disposed of in a landfill.

NOTES

MANUFACTURER / SUPPLIER

Connelly - GPM, Inc.
Portable Treaters Company

REFERENCES

1) Dravo Corporation, "Handbook of Gasifiers and Gas Treatment Systems", ERDA Report FE-1772-11, (Feb. 1976).
2) Riesenfeld, Fred and Kohl, Arthur, Gas Purification, Gulf Publishing Co., Houston (2nd Ed. 1974).
3) Connelly - GPM, Inc., personal communication.

CLASSIFICATION	GENERIC DEVICE OR PROCESS
Fuel Cleaning	Fuel Gas Treatment (Liquid Phase Oxidation)

SPECIFIC DEVICE OR PROCESS	NUMBER
Stretford Process	7.5.3.10

POLLUTANTS CONTROLLED		AIR GASES		AIR PARTICULATES		WATER DISSOLVED		WATER SUSPENDED		LAND LEACHABLE		LAND FUGITIVE
x	ORGANIC	x	Sulfur, HCN									
x	INORGANIC	x	H_2S									
	THERMAL											
	NOISE											

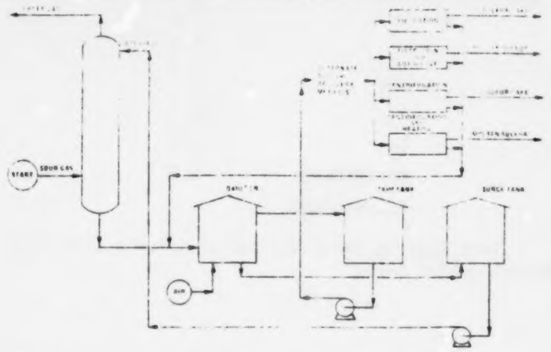


Figure 1. TYPICAL FLOW DIAGRAM OF STRETFORD PROCESS

PROCESS DESCRIPTION

The Stretford solution consists of an aqueous solution of ADA (anthra quinone disulfonic acid) sodium metavanadate, anhydrous citric acid, and sodium carbonate.

The overall chemical reaction of the process is as follows:

$$2H_2S + O_2 \longrightarrow 2S + 2H_2O$$

However, the process actually utilizes the following reaction sequence:

$$H_2S + Na_2CO_3 \longrightarrow NaHS + NaHCO_3$$

$$4NaVO_3 + 2NaH_5 + 2H_2O \longrightarrow Na_2V_4O_9 + 4NaOH$$

$$Na_2V_4O_9 + 2NaOH + H_2O + 2ADA \longrightarrow 4NaVO_3 + \underset{\text{(reduced)}}{2ADA}$$

$$2ADA\ (\text{reduced}) + O_2 \longrightarrow 2ADA + H_2O$$

The rate of absorption of hydrogen sulfide is favored by high pH; however, the rate of conversion of the absorbed hydrogen sulfide to elemental sulfur is adversely affected by pH values above 9.5. The process is therefore best operated with the pH range of 8.5 to 9.5.

A schematic flow diagram of the Stretford process is shown in Figure 1. The raw gas is contacted countercurrently with the solution in the absorber where practically all hydrogen sulfide is removed. The treated gas contains less than 1 ppm of hydrogen sulfide. The solution flows from the absorber to a reaction tank where the conversion of hydrosulfide to elemental sulfur is completed. The reaction tank may be the bottom of the absorber or a separate vessel. From the reaction tank the solution flows to the oxidizer where it is regenerated by intimate contact with air, usually in cocurrent flow. In the oxidizer sulfur is separated from the solution by flotation and removed at the top as a froth containing about 10 percent solids. The relatively sulfur free regenerated solution is recycled to the absorber.

The sulfur froth is collected in a tank and subsequently further processed in filters or centrifuges to separate the solution remaining in the froth. In general, it is necessary to wash the sulfur cake with water to recover chemicals contained in the solution and to produce relatively pure sulfur. For reasons of water balance in the system, wash water and water produced by the reaction has to be evaporated either with the gas or in evaporators, depending on the quantity of water involved.

The sulfur cake which contains about 50 to 60 percent solids may be further processed by melting in an autoclave. In this manner high grade liquid or solid sulfur is produced.

APPLICATION RAGE

The process is usually economic for natural gas and industrial gas streams which contain less than 15% H_2S.

OPERATING RANGES	METRIC (SI)		ENGLISH	
TEMPERATURE	27-49	°C	80-120	°F
PRESSURE	100-6900	KPa	15-1000	psi
VOLUMETRIC RATE		m³/s		ft³/min
MASS RATE		kg/s		lb/hr
ENERGY RATE		J/s		BTU/hr

CAPITAL COSTS

The capital cost of a 5 MMSCFD plant designed to process a feed gas of the following composition is estimated to cost $800,000[A] in 1977 dollars.

	Mole %
H_2S	0.6
CO_2	4.1
CO	27.7
H_2	15.8
CH_4	2.7
N_2	48.7
O_2	0.2
Non-methane Hydrocarbons	0.2

This cost is the installed cost for a plant producing sulfur cake.

OPERATING EFFICIENCIES

The Stretford process can reduce H_2S concentrations in the purified gas to less than 1[2] ppm. A large proportion of the methyl mercaptan is removed by the process but COS and CS_2 are not removed to a significant degree.

OPERATING COSTS

Daily utility requirements based on 5 MMSCFD of feed gas are as follows:[B]

Soda Ash	120 lb/day
Electricity	75 KW/day
Process Water	1 GPM
Stretford Solution	5 lb/day
	($15/day 1977 dollars)
Operating Labor	1 Man/shift

ENVIRONMENTAL PROBLEMS

An effluent stream of Stretford solution is required to prevent excess build up of cyanates and thiosalts. This stream contains vanadium salts, sodium thiocyanate and sodium thiosulfate and therefore it must be treated prior to discharge. Alternative methods for treating this stream include:

Biodegradation
Evaporation
Combustion
Recovery
Adsorption
Ion Exchange

NOTES

A. Verbal communication with licensors.

B. Holmes-Stretford Process.

MANUFACTURER / SUPPLIER

Woodall-Duckham Limited
Peabody Engineering Systems
Black, Sivalls and Bryson, Inc.

REFERENCES

1) Dravo Corporation, "Handbook of Gasifiers and Gas Treatment Systems", ERDA Report FE-1772-11, (Feb. 1976).
2) Riesenfeld, Fred and Kohl, Arthur, Gas Purification, Gulf Publishing Co., Houston (2nd Ed. 1974).
3) Radian Corp., "Technology Status Report, Low/Medium - BTU Coal Gasification and Related Environmental Controls", performed under EPA Contract No. 68-02-2147 (June 1977).
4) Catalytic, Inc., "The Stretford Process", performed under EPA Contract No. 68-02-2167, (January 1978).

CLASSIFICATION Fugitive Emissions Control	**GENERIC DEVICE OR PROCESS** Dust Control Sprays (Chemical Agents)	
SPECIFIC DEVICE OR PROCESS Petroleum Resins		**NUMBER** 8.3.3.2

	POLLUTANTS CONTROLLED	**AIR**		**WATER**		**LAND**	
		GASES	**PARTICULATES**	**DISSOLVED**	**SUSPENDED**	**LEACHABLE**	**FUGITIVE**
x	**ORGANIC**		X				X
X	**INORGANIC**		x				X
	THERMAL						
	NOISE						

PROCESS DESCRIPTION

Wind erosion of soil increases in severity as the size of the soil particles decreases. Resinous adhesive dust retardents have been developed to bind together the small soil particles and create a larger effective average diameter. This reduces soil movement by saltation, creep, and suspension, the three mechanisms of wind erosion. The retardent is manufactured as a cold water emulsion so that it can be diluted with water and applied with conventional spraying equipment.

Some tests have shown the agent to be compatible with both germinating and growing plants, so that it can be used to stabilize soil in mined land reclamation operations. After the area to be reclaimed is seeded, dust retardent is applied to hold seed and fertilizer in place until germination occurs and then protect young seedlings from being destroyed by moving sand and dust.

APPLICATION RANGE

Applicable to both soil dust and coal dust on coal mine roads. Also used to prevent blowing of coal fines from railroad hopper cars. Used for stabilization of mine tailings from various types of mining operations. Also used to stabilize overburden from stripping operations.

OPERATING RANGES	METRIC (SI)	ENGLISH
TEMPERATURE	°C	°F
PRESSURE	KPa	psi
VOLUMETRIC RATE	m^3/s	ft^3/min
MASS RATE	kg/s	lb/hr
ENERGY RATE	J/s	BTU/hr

CAPITAL COSTS

Depending on the application, capital investment may be necessary, such as spray trucks for haul road treatment, or a stationary spray system for conveyors, piles, tailings dumps, etc. In other cases, available systems may be used to apply the chemical.

OPERATING COSTS

Typical costs (1976) for haul road application have been given as $3500 per mile for initial application and $2000 per mile per year thereafter. Costs for treating tailings pond sites have been given as $178/acre. Bulk cost of the chemical itself may be in the range 40-50 cents per gallon.

OPERATING EFFICIENCIES

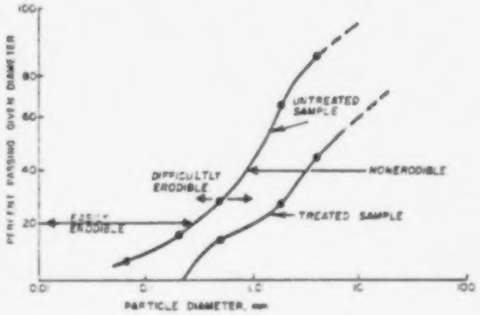


Figure 1. EFFICIENCY OF INCREASING PARTICLE SIZE[1].

ENVIRONMENTAL PROBLEMS

Contamination of streams could occur where treated soil or dust is washed into streams by rainfall.

NOTES

MANUFACTURER / SUPPLIER

Golden Bear Division, Witco Chemical Corp.
Easton R/S Corp.
Nalco Chemical Co.
Arcal Chemicals, Inc.

REFERENCES

1) Canessa, W., "Chemical Retardants Control Fugitive Dust Problems", Pollution Engineering, July 1977, p. 24.

SECONDARY ENTRY SYSTEM-EXAMPLES

AIR POLLUTION	GASEOUS POLLUTANTS					PARTICULATES	
INDUSTRY/POLLUTANT STREAM	SULFUR COMPOUNDS	NITROGEN COMPOUNDS	ORGANICS	CARBON MONOXIDE	OTHER	SOLIDS	LIQUIDS
Synthetic Fuels - High BTU Gasification							
Fugitive Gasifier Ash						5.3 (2,3) 8.1.3 8.2 (1-3) 8.3 (1-3) 8.4 (1,2)	
Ash Quench Gases			5.1.1			1.1 (1-3) 1.2 (1-3) 1.3.2 1.4 (2-6,11)	1.3 (3,4) 1.4 (2-6,11) 1.5.2
Lock Hopper Gases	1.4(1-3,6-10) 1.6 (1-3) 1.7 (1,2) 7.5 (1-5)	1.8 (1,2)	1.7 (1,2)	1.7 (1,2)		1.1 (1,3) 1.2 (1,2) 1.3 (1-4) 1.4 (1-6,11)	
Crude Synthetic Gas	7.1 (1-7) 7.5 (1-5)	1.5 (1,2)	1.5 (1,2) 5.3.1 9.4 (1-3)			1.1 (1,3) 1.2 (1,2) 1.4 (2-6,11)	
Fugitive Crude Gas	8.4.1 8.5 (5-7) 8.6 (3,4)	8.4.1 8.5 (5-7) 8.6 (3,4)	8.4.1 8.5 (5-7) 8.6 (3,4)	8.4.1 8.5 (5-7) 8.6 (3,4)			
Flare Emissions	4.6.1 5.3 (1,3,4) 6.4.2	4.6.1 5.3 (1,3,4)		4.6.1 5.3 (1,3,4)		4.6.1 5.3 (1,3,4) 6.4.1	
Lean H_2S Flash Gas	1.4 (1,2,7-9) 1.6 (1-3) 1.7 (1,2) 4.6.1 7.5 (1-5)		1.7 (1,2) 4.6.1	1.4.1 1.7 (1,2) 4.6.1			
Rich H_2S Gas	1.4 (1,2,7-9) 1.6 (1-3) 1.7 (1,2) 7.5 (1-5)		1.7 (1,2)	1.4.1 1.7 (1,2)			

AIR POLLUTION	GASEOUS POLLUTANTS					PARTICULATES	
INDUSTRY/POLLUTANT STREAM	SULFUR COMPOUNDS	NITROGEN COMPOUNDS	ORGANICS	CARBON MONOXIDE	OTHER	SOLIDS	LIQUIDS
Synthetic Fuels - High BTU Gasification (Cont.)							
Expansion Gas	1.4(1,2,7-9) 1.6 (1-3) 1.7 (1,2) 4.6.1 7.5 (1-5)		1.7 (1,2) 4.6.1 5.3.1 9.4 (1-3)	1.4.1 1.7 (1,2) 4.6.1 5.3.1 9.4 (1-3)			
CO_2 Vent Gas			1.6 (1-3) 1.7 (1,2) 4.6.1	1.4.1 1.7 (1,2) 4.6.1			
Nickle Carbonyl Contamination of SNG					5.2.1 5.3 (4,6)		
Spent Catalyst Regeneration Gases							
Acid Gases	1.4(1,2,7-9) 1.6 (1-3) 1.7 (1,2) 7.5 (1-5)						
Fugitive Tar, Tar Oil, Phenol and Naphtha Emissions			1.4 (7,8) 1.5 (1,2) 1.6 (1-3) 1.7 (1,2) 8.1.3 8.4.1 8.5 (5-7) 8.6 (1,4) 8.7 (1-9)				
Fugitive Ammonia Emissions					1.4 (7-9) 8.1.3 8.5 (5-7) 8.6 (3,4) 8.7 (7,8)		
Sulfur Plant Tail Gas	1.4(1,2,7-9) 1.6 (1-3) 1.7 (1,2) 1.8.2 4.6.1 7.5 (1-5)		1.6 (1-3) 1.7 (1,2) 4.6.1	1.4.1 1.7 (1,2) 4.6.1			

AIR POLLUTION	GASEOUS POLLUTANTS					PARTICULATES	
INDUSTRY/POLLUTANT STREAM	SULFUR COMPOUNDS	NITROGEN COMPOUNDS	ORGANICS	CARBON MONOXIDE	OTHER	SOLIDS	LIQUIDS
Synthetic Fuels - High BTU Gasification (Cont.)							
Sulfur Plant Incinerator Offgas	1.4(1,2,7-9) 1.6 (1-3) 4.6.1	6.1 (1-6,8)		5.3.4			
Fugitive Sulfur Emissions	1.5 (1,2) 8.4.1 8.5(2,3,5-7) 8.6.4 8.7 (5,7-9)						
Natural Gas Processing							
Fugitive Gas Emissions	8.5(3,5-7) 8.6 (3-4) 8.7.7		8.5 (3,5-7) 8.6 (3,4) 8.7.7				
Untreated Acid Gas	1.4(1,2,7-9) 1.6 (1-3) 1.7 (1,2) 4.6.1 7.5 (1-5)						
Sulfur Recovery Plant Tail Gas	1.4(1,2,7-9) 1.6 (1-3) 1.7 (1,2) 1.8.2 4.6.1 7.5 (1-5)		1.6 (1-3) 1.7 (1,2) 4.6.1	1.4.1 1.7 (1,2) 4.6.1			
Dehydration Process Offgas			1.5 (1,2) 1.6 (1-3) 1.7.2 4.6.1				
Fugitive LPG Loading Emissions			8.5 (3,5-7) 8.6 (2-4) 8.7 (7,8)				
Fugitive Liquid Hydrocarbon Emissions			1.5 (1,2) 1.6 (1-3) 8.7 (1-9)				

AIR POLLUTION	GASEOUS POLLUTANTS					PARTICULATES	
INDUSTRY/POLLUTANT STREAM	SULFUR COMPOUNDS	NITROGEN COMPOUNDS	ORGANICS	CARBON MONOXIDE	OTHER	SOLIDS	LIQUIDS
Petroleum Refining							
Storage Tank Emissions			1.5 (1,2) 1.6 (1-3) 8.7 (1-9)				
Fugitive Crude and Distillate Emissions			2.1 (6,7) 2.2.5 2.3 (1-4) 2.4 (3,4) 8.1 (1,3) 8.4 (1,2) 8.5 (2-7) 8.6 (1,2,4) 8.7 (2,7) 8.8 (1,2) 8,10 (1-3)				
Fugitive Petroleum Gas			8.5(2,3,5-7) 8.6 (3,4)				
Untreated Refinery Tail Gas	1.4(1,2,7-9) 1.7 (1,2) 4.6.1 7.5 (1-5)		1.7 (1,2)	1.7 (1,2)			
Sour Gas	1.4(1,2,7-9) 1.7 (1,2) 4.6.1 7.5 (1-5)		1,7 (1,2)	1.7 (1,2)			
Sulfur Recovery Plant Tail Gas	1.4(1,2,7-9) 1.6 (1-3) 1.7 (1,2) 1.8.2 4.6.1 7.5 (1-5)		1.6 (1-3) 1.7 (1,2) 4.6.1	1.4.1 1.7 (1,2) 4.6.1			
Barometric Condensor Offgas	7.5 (1-5)		1.7 (1,2) 4.6.1				
Catalyst Regeneration Offgas	1.4(1,2,7-10) 1.7 (1,2)		1.7 (1,2)	1.4.1 1.7 (1,2)		1.1 (1,3) 1.2 (1,2) 1.3 (1,2) 1.4(3-6,11)	

AIR POLLUTION	GASEOUS POLLUTANTS					PARTICULATES	
INDUSTRY/POLLUTANT STREAM	SULFUR COMPOUNDS	NITROGEN COMPOUNDS	ORGANICS	CARBON MONOXIDE	OTHER	SOLIDS	LIQUIDS
Petroleum Refining (Cont.)							
FCC Regenerator Offgas	1.4(1,2,7-10) 1.6 (1-3) 1.8.2 4.6.1 7.5 (1-5)	1.4.1 1.8 (1,3)	1.7 (1,2) 4.6.1 5.3.4	1.7 (1,2) 4.6.1 5.3.4		1.1 (1,3) 1.2 (1,2) 1.3 (1,2) 1.4 (3-6,11) 4.6.1	
TCC Kiln Flue Gas	1.4(1,2,7-10) 1.6 (1-3) 1.8.2 4.6.1 7.5 (1-5)	1.4.1 1.8 (1,3)	1.7 (1,2) 4.6.1 5.3.4	1.7 (1,2) 4.6.1 5.3.4		1.1 (1,3) 1.2 (1,2) 1.3 (1,2) 1.4 (3-6,11) 4.6.1	
Fugitive Catalyst Dust						4.3 (1,2) 8.3 (1-3) 8.4 (1,2)	
Fugitive Cleaning Acid Emissions	8.4 (1,2) 8.5 (4-7) 8.6.4				8.4 (1,2) 8.5 (4-7) 8.6.4		
Depropanizer Accumulator Offgas			1.7 (1,2)		1.4(1,2,6-9)		
Fugitive HF Alkylation Offgas			8.4 (1,2) 8.5(2,3,5-7) 8.6 (3,4)		8.4 (1,2) 8.5(2,3,5-7) 8.6 (3,4)		
Asphalt Blowing Offgas			1.4 (1-11) 1.7 (1,2)				
Coker Offgas	1.7 (1,2) 4.6.1 7.5 (1-5)		1.7 (1,2) 4.6.1	1.7 (1,2) 7.5 (1-5)		1.1 (1,3) 1.2 (1,2)	
Fugitive Petroleum Coke						8.3 (1-3) 8.4 (1,2)	
Coke Cutting Water Odors						8.4.1 8.10 (1-3)	
Process Heater Offgas	1.4(1,2,7-10) 1.6 (1-3) 1.8.2 4.6.1	1.4.1 1.8 (1,3) 4.6.1 6.1 (1-6,8)	4.6.1 5.3.4	4.6.1 5.3.4			

AIR POLLUTION	GASEOUS POLLUTANTS					PARTICULATES	
INDUSTRY/POLLUTANT STREAM	SULFUR COMPOUNDS	NITROGEN COMPOUNDS	ORGANICS	CARBON MONOXIDE	OTHER	SOLIDS	LIQUIDS
Petroleum Refining (Cont.)							
Process Heater Offgas (Cont.)	6.3 (1-3) 6.4.2 7.5 (1-5)	6.4.4					
Pressure Relief Emissions			8.5.7 8.6 (3,4) 9.4 (1-3)				
Flare Emissions	4.6.1 6.4.2 9.4.1	4.6.1 6.4.4 9.4.1	4.6.1 5.3.4 6.4.1 9.4.1	4.6.1 5.3.4 9.4.1			
Boiler Stack Emissions	1.4(1,2,7-10) 1.6 (1-3) 1.8.2 4.6.1 6.3 (1-3) 6.4.2 7.4 (1-3) 7.5 (1-5)	1.4.1 1.8 (1,2) 4.6.1 6.1 (1-6,8) 6.2 (1-5) 6.4.4	4.6.1 5.3.4 6.4.1	4.6.1 5.3.4			
Gas Fired Engine Exhaust	7.5 (1-5)	1.8.1					
CO Boiler Offgas		1.8.1 6.1 (1-6,8) 6.2 (1-5)		5.3.4			

LAND POLLUTION							
INDUSTRY/POLLUTANT STREAM	ORGANIC	SOLUBLE INORGANIC	FUGITIVE DUST	INERT WASTES			
Synthetic Fuels - High BTU Gasification							
Gasifier Ash		4.3 (1,2)	4.3 (1,2)	4.3 (1,2)			
Spent Shift Catalyst		4.3 (1,2) 4.4 (1-3)	4.3 (1,2)	4.3 (1,2)			
Spent Methanation Catalyst		5.2.2	4.3.1				
Spent Sulfur Plant Catalyst		4.3 (1,2) 4.4 (1-3) 5.2.2	4.3 (1,2)	4.3 (1,2)			
Scrubber Wastes		3.1 (1-3) 4.3 (1,2)	4.3 (1,2)	4.3 (1,2)			
Natural Gas Processing							
Spent Sulfur Recovery Catalyst		3.2 (1,2) 4.3 (1,2) 4.4 (1-3) 5.2.2	3.2.2 4.3 (1,2) 4.4 (1-3) 5.2.2	3.2.2 4.3 (1,2) 4.4 (1-3) 5.2.2			
Petroleum Refining							
Spent Sulfur Recovery Catalyst		3.2 (1,2) 4.3 (1,2) 4.4 (1-3) 5.2.2	3.2.2 4.3 (1,2) 4.4 (1-3) 5.2.2	3.2.2 4.3 (1,2) 4.4 (1-3) 5.2.2			
Spent Processing Catalyst	3.3 (1-6) 3.6.8	3.2 (1,2) 4.3 (1,2) 4.4 (1-3) 5.2.2	3.2.2 4.3 (1,2) 4.4 (1-3) 5.2.2	3.2.2 4.3 (1,2) 4.4 (1-3) 5.2.2			
HF Scrubber Sludge		4.3 (1,2) 4.4 (1-3)	4.3 (1,2) 4.4 (1-3)	4.3 (1,2) 4.4 (1-3)			
Acid Regeneration Sludge	3.3 (1-6) 3.6.8	4.3 (1,2) 4.4 (1-3)	4.3 (1,2) 4.4 (1-3)	4.3 (1,2) 4.4 (1-3)			
Spent Polymevization Acid Catalyst		3.1.3 4.3 (1,2) 4.6.3 4.7.2 5.2 (1,2)					

LAND POLLUTION							
INDUSTRY/POLLUTANT STREAM	ORGANIC	SOLUBLE INORGANIC	FUGITIVE DUST	INERT WASTES			
Petroleum Refining (Cont.)							
Lube Oil Acid Sludge		3.1.3 4.3 (1,2) 4.4 (2,3)					
Wastewater Treatment Sludge	3.3 (1-6) 3.5 (2,3) 4.3 (1,2)						

WATER POLLUTION	DISSOLVED				SUSPENDED		
INDUSTRY/POLLUTANT STREAM	INORGANICS	PH	TOXIC SUBSTANCES	ORGANICS	SOLIDS	OILS	THERMAL
Synthetic Fuels - High BTU Gasification							
Ash Quench Water	2.6 (1-7) 2.7.4 2.12 (1-5) 2.14 (1,2) 2.16 (1,2) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3,4) 7.1 (1-7)	2.9 (1,2) 2.10 (1,3,4) 2.14 (1,2) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 5.2 (1,2) 5.3 (1,3,4) 7.1 (1-7)	2.6 (1-7) 2.7.4 2.8 (1-6) 2.12 (1-5) 2.13 (1-4) 2.14 (1,2) 2.16 (1,2) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 5.2 (1,2) 5.3 (1,3,4) 7.1 (1-7)	2.6 (1-7) 2.7.4. 2.8 (1-8) 2.9 (1,2) 2.11 (1-5) 2.12 (1-5) 2.13 (1-4) 2.16 (1,2) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3,4) 7.1 (1,7)	2.1 (1-5) 2.2 (1-8) 2.3 (1-4) 2.4 (1-4) 2.5 (1-15) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 5.2 (1,2) 5.3 (1,3,4) 7.1 (1-7)	2.1 (5,6) 2.3 (1-4) 2.7.4 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 5.1.1 5.2 (1,2) 5.3 (1,3,4)	2.6 (1-3) 2.15(1-3) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 4.7.3 5.2 (1,2) 5.3 (1,3,4)
Waste Heat Boiler Blowdown	2.12 (1-5) 2.14 (1,2) 4.1 (1-3) 4.5 (1,2) 5.1.1 5.2 (1,2) 5.3 (1-4)			2.11 (1-5) 2.12 (1-5) 2.13 (1-4) 4.1 (1-3) 4.5 (1,2) 5.1.1 5.2 (1,2) 5.3 (1-4)	2.1 (1-5) 2.5 (7-15, 7-19) 4.1 (1-3) 4.5 (1,2) 5.1.1 5.2 (1,2) 5.3 (1-4)		2.5 (1-6) 2.15 (1-3) 4.1 (1-3) 4.5 (1,2) 4.6.2 4.7.3 5.2 (1-3) 5.3 (1-4)
Process Condensate	2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 2.9 (1,2) 2.12 (1-5) 2.14 (1,2) 2.15 (1,3) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3,4)	2.9 (1,2) 2.10 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 5.2 (1,2) 5.3 (1,3,4)	2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3,4)	2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 2.9 (1,2) 2.11 (1-5) 2.12 (1-5) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3,4)	2.1 (1-5) 2.2 (1-4, 6-8) 2.3 (1-4) 2.5 (7-15) 2.6 (1-6) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3,4)	2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3,4)	2.6 (1-7) 2.15 (1-3) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 4.7.3 5.2 (1-3) 5.3 (1,3,4)

WATER POLLUTION	DISSOLVED				SUSPENDED		
INDUSTRY/POLLUTANT STREAM	INORGANICS	PH	TOXIC SUBSTANCES	ORGANICS	SOLIDS	OILS	THERMAL
Synthetic Fuels - High BTU Gasification (Cont.)							
Fugitive Tar, Tar Oil and Phenol Emissions			2.8 (1-6) 2.11 (1-5) 2.12 (1-5) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1-4) 8.5 (1-5) 8.6 (1,4) 9.1 (1-5)	2.8 (1-6) 2.11 (1-5) 2.12 (1-5) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1-4) 8.5 (1-5) 8.6 (1,4) 9.1 (1-5)		2.1 (5-7) 2.5.14 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 5.2 (1,2) 5.3 (1-4) 8.5 (1-5) 8.6 (1,4) 9.1 (1-5) 9.5 (1-4) 9.6 (1-8) 9.7 (1-5) 9.8.1	
Fugitive Naphtha Emissions				2.11 (1-5) 2.12 (1-5) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1-4) 8.5 (1-5) 8.6 (1,4) 9.1 (1-5)		2.1 (5-7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 2.5.14 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 5.2 (1,2) 5.3 (1-4) 8.5 (1-5) 8.6 (1,4) 9.1 (1-5) 9.5 (1-4) 9.6 (1-8) 9.7 (1-5) 9.8.1	
Sulfur Recovery Plant Blowdown			2.16.1	2.16.1			
Sulfur Recovery Plant Condensate			2.6 (2-6) 2.7 (1-4) 2.9 (1,2) 5.2 (1,2)				

WATER POLLUTION	DISSOLVED				SUSPENDED		
INDUSTRY/POLLUTANT STREAM	INORGANICS	PH	TOXIC SUBSTANCES	ORGANICS	SOLIDS	OILS	THERMAL
Synthetic Fuels - High BTU Gasification (Cont.)							
Fugitive Sulfur Emissions					2.1 (1-5) 2.3 (1-4) 2.4 (1-4, 7-16) 8.5 (2,3, 5-7) 8.6.4 9.1.5		
Natural Gas Processing							
Spent Absorption Solution				2.11 (1-5) 2.12 (1-5) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1-4) 7.5 (1-5)			
Dehydration Process Wastewater				2.8 (1-6) 2.11 (1-5) 2.12 (1-5) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2)			
Fugitive Natural Gasoline Emissions				2.11 (1-5) 2.12 (1-5) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1-4)		2.1 (5-7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 2.5.14 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 5.2 (1,2)	

WATER POLLUTION	DISSOLVED				SUSPENDED		
INDUSTRY/POLLUTANT STREAM	INORGANICS	PH	TOXIC SUBSTANCES	ORGANICS	SOLIDS	OILS	THERMAL
Natural Gas Processing (Cont.)							
Fugitive Natural Gasoline Emissions (Cont.)				8.5 (1-5) 8.6 (1,4) 9.1 (1-5)		5.3 (1-4) 8.5 (1-5) 8.6 (1,4) 9.1 (1-5) 9.5 (1-4) 9.6 (1-8) 9.7 (1-5) 9.8.1	
Petroleum Refining							
Crude Storage Draws (BS&W)	2.2.1 2.5 (17-19) 2.6 (1-7) 2.14 (1,2) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2			2.6 (2-6) 2.8 (1-6) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2	2.1 (1,2,5) 2.2 (1-4, 6-8) 2.3 (1-4) 2.4 (1-4) 2.5 (7-19) 2.6 (1-7) 2.11 (1-5) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2	2.1(1,2,5-7) 2.2 (2-5) 2.3 (1-4) 2.4 (3,4) 2.5.14 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3)	
Desalting Water	2.2.1 2.5 (17-19) 2.6 (1-7) 2.14 (1,2) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2			2.6 (2-6) 2.8 (1-6) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2	2.1 (1,2,5) 2.2 (1-4, 6-8) 2.3 (1-4) 2.4 (1-4) 2.5 (7-19) 2.6 (1-7) 2.11 (1-5) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2	2.1(1,2,5-7) 2.2 (2-5) 2.3 (1-4) 2.4 (3,4) 2.5.14 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3)	

WATER POLLUTION	DISSOLVED				SUSPENDED		
INDUSTRY/POLLUTANT STREAM	INORGANICS	PH	TOXIC SUBSTANCES	ORGANICS	SOLIDS	OILS	THERMAL
Petroleum Refining (Cont.)							
Fugitive Crude and Distillate			2.8 (1-6) 2.11 (1-5) 2.12 (1-5) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1-4) 8.5 (1-5) 8.6 (1,4) 9.1 (1-5)	2.8 (1-6) 2.11 (1-5) 2.12 (1-5) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1-4) 8.5 (1-5) 8.6 (1,4) 9.1 (1-5)		2.1 (5-7) 2.5.14 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 5.2 (1,2) 5.3 (1-4) 8.5 (1-5) 8.6 (1,4) 9.1 (1-5) 9.5 (1-4) 9.6 (1-8) 9.7 (1-5) 9.8.1	
Condensed Stripping Steam	2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 2.9 (1,2) 2.12 (1-5) 2.14 (1,2) 2.15 (1,3) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)	2.9 (1,2) 2.10 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 5.2 (1,2) 5.3 (1,3-5)	2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 2.9 (1,2) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)	2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 2.9 (1,2) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)		2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)	2.6 (1-7) 2.15 (1-3) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 4.7.3 5.2 (1-3) 5.3 (3-5)
Spent Amine Solution				2.11 (1-5) 2.12 (1-5) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1-4) 7.5 (1-5)			
Caustic Washes		2.10(1,3,4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2)		2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2)		2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 4.1 (1-3)	

WATER POLLUTION	DISSOLVED				SUSPENDED		
INDUSTRY/POLLUTANT STREAM	INORGANICS	PH	TOXIC SUBSTANCES	ORGANICS	SOLIDS	OILS	THERMAL
Petroleum Refining (Cont.)							
Caustic Washes (Cont.)		4.7.2 5.2 (1,2) 5.3(1,3,4,6)		4.4 (1-3) 4.5 (1,2) 4.7.2 5.2 (1,2) 5.3(1,3,4,6)		4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.7.2 5.2 (1,2) 5.3(1,3,4,6)	
Acid Treating Effluent		2.10 (1,2,4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.7.1 5.2.1 5.3(1,3,4,6)		2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.7.1 5.2.1 5.3(1,3,4,6)		2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.7.1 5.2.1 5.3(1,3,4,6)	
Water Washes		2.10 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3(1,3,4,6)		2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3(1,3,4,6)		2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3(1,3,4,6)	
Jet and Barometric Condenser Water	2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 2.9 (1,2) 2.12 (1-5) 2.14 (1,2) 2.15 (1,3) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)	2.9 (1,2) 2.10 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 5.2 (1,2) 5.3 (1,3-5)	2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 2.9 (1,2) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)	2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 2.9 (1,2) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)		2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)	2.6 (1-7) 2.15 (1-3) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 4.7.3 5.2 (1-3) 5.3 (3-5)

WATER POLLUTION	DISSOLVED				SUSPENDED		
INDUSTRY/POLLUTANT STREAM	INORGANICS	PH	TOXIC SUBSTANCES	ORGANICS	SOLIDS	OILS	THERMAL
Petroluem Refining (Cont.)							
Isomerization Neutralizer Waste	4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5.1 5.2.2 5.3 (1,3-6)	2.10 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5.1 5.2.2 5.3 (1,3-6)		4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5.1 5.2.2 5.3 (1,3-6)	4.1 (1-3) 4.3 (1,2) 4.4 (1-3) 4.5.1 5.2.2 5.3 (1,3-6)		
Alkylate Treatment Waste		2.10 (1,3,4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.7.2 5.2 (1,2) 5.3(1,3,4,6)		2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.7.2 5.2 (1,2) 5.3(1,3,4,6)		2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.7.2 5.2 (1,2) 5.3 (1,3,4,6)	
Chemical Sweetening Waste	2.2.1 2.6 (1-7) 2.7.4 2.8 (1-6) 2.9 (1,2) 2.14 (1,2) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.7.2 5.2 (1,2) 5.3 (1,3,4,6)	2.10 (1,3,4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.7.2 5.2 (1,2) 5.3 (1,3,4,6)		2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.7.2 5.2 (1,2) 5.3(1,3,4,6)		2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.7.2 5.2 (1,2) 5.3(1,3,4,6)	
Sweetening Wash Water	2.2.1 2.6 (1-7) 2.7.4 2.8 (1-6) 2.9 (1,2) 2.14 (1,2) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3)	2.10 (1,3,4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 5.2 (1,2) 5.3(1,3,4,6)		2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 5.2 (1,2) 5.3(1,3,4,6)		2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 5.2 (1,2)	

WATER POLLUTION	DISSOLVED				SUSPENDED		
INDUSTRY/POLLUTANT STREAM	INORGANICS	PH	TOXIC SUBSTANCES	ORGANICS	SOLIDS	OILS	THERMAL
Petroleum Refining (Cont.)							
Sweeteining Wash Water (Cont.)	4.5 (1,2) 5.2 (1,2) 5.3(1,3,4,6)					5.3(1,3,4,6)	
Hydrocracking Separator Liquor	2.6 (3-6) 2.7 (1-4) 2.9 (1,2) 2.12 (1-5) 2.15 (1,3) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)	2.6 (3-6) 2.7 (1-4) 2.9 (1,2) 2.12 (1-5) 2.15 (1,3) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)					
Lube Oil Processing Waste				2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2)		2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 2.5.14 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 5.2 (1,2)	
Coke Accumulator Water	2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 2.9 (1,2) 2.12 (1-5) 2.14 (1,2) 2.15 (1,3) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)	2.9 (1,2) 2.10 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 5.2 (1,2) 5.3 (1,3-5)		2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 2.9 (1,2) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)		2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)	2.6 (1-7) 2.15 (1-3) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 4.7.3 5.2 (1-3) 5.3 (3-5)

WATER POLLUTION	DISSOLVED				SUSPENDED		
INDUSTRY/POLLUTANT STREAM	INORGANICS	PH	TOXIC SUBSTANCES	ORGANICS	SOLIDS	OILS	THERMAL
Petroleum Refining (Cont.)							
Coke Drum Steaming Condensate				2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)	2.1 (1-5) 2.2 (1-4, 6-8) 2.3 (1-4) 2.4 (1-4) 2.5 (7-16) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 5.2 (1,2) 5.3 (1,3-5)	2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 2.5.14 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 5.2 (1,2) 5.3 (1,3-5)	
Coke Drum Quench Water				2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2) 5.3 (1,3-5)	2.1 (1-5) 2.2 (1-4, 6-8) 2.3 (1-4) 2.4 (1-4) 2.5 (7-16) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 5.2 (1,2) 5.3 (1,3-5)		
Coke Cutting Water					2.1 (1-5) 2.2 (1-4, 6-8) 2.3 (1-4) 2.4 (1-4) 2.5 (7-16) 4.1 (1-3) 4.5 (1,2) 5.2 (1,2) 5.3 (1,3-5)		
Gasoline Tank Draws				2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2)		2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 2.11 (1-5)	

WATER POLLUTION	DISSOLVED				SUSPENDED		
INDUSTRY/POLLUTANT STREAM	INORGANICS	PH	TOXIC SUBSTANCES	ORGANICS	SOLIDS	OILS	THERMAL
Petroleum Refining (Cont.)							
Gasoline Tank Draws (Cont.)				4.4 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2)		2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 5.2 (1,2)	
Ballast Water				2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2) 8.8 (1,2)		2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 5.2 (1,2) 8.8 (1,2)	
Tank Cleaning Wastes	2.2.1 2.5 (17-19) 2.6 (1-7) 2.14 (1,2) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2			2.6 (2-6) 2.8 (1-6) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2	2.1 (1,2,5) 2.2 (1-4, 6-8) 2.3 (1-4) 2.4 (1-4) 2.5 (7-19) 2.6 (1-7) 2.11 (1-5) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3) 4.5 (1,2) 4.6.2	2.1 (1,2,5-7) 2.2 (2-5) 2.3 (1-4) 2.4 (3,4) 2.5.14 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.4 (1-3)	
Catalyst Regeneration Condensate	2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 2.9 (1,2) 2.12 (1-5) 2.15 (1,3) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2	2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 2.9 (1,2) 2.12 (1-5) 2.15 (1,3) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2	2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 2.9 (1,2) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2)	2.6 (1-7) 2.7 (1-4) 2.8 (1-6) 2.9 (1,2) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2)	2.1 (1-5) 2.2 (1-4, 6-8) 2.3 (1-4) 2.4 (1-4) 2.5 (7-16) 4.1 (1-3) 4.5 (1,2) 4.6.2 5.2 (1,2)	2.1 (6,7) 2.2 (2,3,5) 2.3 (1-4) 2.4 (3,4) 2.11 (1-5) 2.12 (1-6) 2.13 (1-4) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2)	2.6 (1-7) 2.15 (1-3) 4.1 (1-3) 4.2 (1,2) 4.5 (1,2) 4.6.2 4.7.3 5.2 (1-3) 5.3 (3-5)

WATER POLLUTION	DISSOLVED				SUSPENDED		
INDUSTRY/POLLUTANT STREAM	INORGANICS	PH	TOXIC SUBSTANCES	ORGANICS	SOLIDS	OILS	THERMAL
Petroleum Refining (Cont.)							
Catalyst Regeneration Condensate	5.2 (1,2) 5.3 (1,3-5)	5.2 (1,2) 5.3 (1,3-5)	4.6.2 5.2 (1,2) 5.3 (1,3-5)	4.6.2 5.2 (1,2) 5.3 (1,3-5)		4.6.2 5.2 (1,2) 5.3 (1,3-5)	